International Journal of Psychophysiology 129 (2018) 18–30

Contents lists available at ScienceDirect

International Journal of Psychophysiology

journal homepage: www.elsevier.com/locate/ijpsycho

Heart rate variability response to affective pictures processed in and outside of conscious awareness: Three consecutive studies on emotional regulation

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ABSTRACT

Previous research has increased understanding of the neurobiological basis of emotional regulation. However, less is known concerning the unconscious processing of affective information. Three experiments were performed to investigate the extent to which complex affective stimuli can be processed outside of consciousness and demonstrate possible mechanisms for regulation of resulting emotional responses. In Experiment 1, participants were either instructed to passively observe blocked-picture cues (neutral and negative) or to down-regulate their emotions by distancing. Resulting emotional regulation activity was assessed with 0.1-Hz heart rate variability (HRV) indices. In Experiment 2, participants were presented with affective pictures that were rendered consciously invisible by means of continuous flash suppression (CFS). In Experiment 3, two equivalent sets of negative affective pictures were covertly presented and the effect of a cognitive task on emotional regulation was evaluated. Our findings revealed that 0.1-Hz HRV indices exhibited greater change over baseline in response to negative compared to neutral stimuli for both presentation conditions (consciously perceived or not). The implementation of distancing and the cognitive task were both associated with higher 0.1-Hz HRV change scores. These results indicate that even complex affective stimuli can be processed without awareness, resulting in a congruent emotional response that is physiologically detectable. Cognitive strategies can help more effectively regulate this response, implying that conscious perception of a triggering stimulus may not be essential for cognitive regulation.

1. Introduction

1.1. Emotional regulation and heart rate variability

Emotional dysregulation plays a central role in the development of many psychiatric disorders (e.g., depression and anxiety disorders) (Gross, 2013). Psychotherapies, including various forms of cognitive behavioural therapy (CBT), employ techniques such as reappraisal and distancing that aim to teach more adaptive strategies for emotional regulation. Studies using a wide range of techniques from functional neuroimaging to the use of psychoactive substances have increased understanding of the anatomical structures and physiological processes involved in emotion and its regulation (Ball et al., 2013; Goldapple et al., 2004; Murphy et al., 2009; van Honk et al., 2005; Vaschillo et al., 2008). The interplay of the amygdala and other limbic structures with the prefrontal and orbitofrontal cortical areas as well as the cingulate cortex have emerged as processes (and areas of the brain) that clearly show activity relevant to emotional regulation on neuroimaging (Buhle et al., 2014; Erk et al., 2010; Kanske et al., 2012; Koenigsberg et al., 2010).

Emotion regulation has also been shown to be linked to heart rate variability (HRV). HRV provides information on the degree of the functional integration in the axis connecting central autonomic network and peripheral physiology. In other words, it reflects the extent to which emotional context provides adjustable control over the peripheral autonomic functioning (Thayer et al., 2012). Previous research has linked increased HRV to the use of adaptive emotional regulation strategies, whereas reduced HRV has been associated with conditions indicative of emotional dysregulation, such as depression and anxiety (Brosschot et al., 2007; Denson et al., 2011; Di Simplicio et al., 2012; Geisler et al., 2010; Miu et al., 2009; Mujica-Parodi et al., 2009). Taken together, the available evidence supports the utility of HRV measurements as an objective and sensitive index of the brain's ability to regulate emotional responses (Appelhans and Luecken, 2006).

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https://doi.org/10.1016/j.ijpsycho.2018.05.006
Received 19 December 2017; Received in revised form 12 May 2018; Accepted 14 May 2018
Available online 19 May 2018
0167-8760/

There are many methods for evaluating HRV, ranging from conventional time or frequency domain measures to more innovative techniques such as the recently introduced 0.1-Hz HRV methodology. Based on the resonance properties of the cardiovascular system at the frequency of 0.1 Hz (which has been shown to be associated with baroreflex activity), this novel technique was developed to stimulate the cardiovascular system with affective stimuli presented at this frequency (i.e. 0.1 Hz, where a stimulus is given every 10 s), inducing high-amplitude resonance heart rate oscillations (Vaschillo et al., 2008; Vaschillo et al., 2006). As a product of the complex interplay between sympathetic and parasympathetic activity, the 0.1-Hz HRV index was reported to be significantly more sensitive to changes in emotional arousal resulting from negatively valenced stimuli than the traditional HRV indices. Moreover, this index was suggested to sensitively reflect both the autonomic response to the stimulus and the subsequent modulatory process, i.e. emotional regulation as a whole. Taken together, 0.1-Hz HRV methodology emerges as a promising and objective means to study emotional regulation under well-defined experimental conditions.

1.2. Unconscious emotional processing

Most of the experimental research on emotional regulation investigated reactions to consciously perceived visual stimuli, leaving important questions unanswered concerning the unconscious processing of affective information. It is important to note that, when talking about unconscious processes, cognitive neuroscientists refer to very different mental phenomena than those studied by psychoanalysts. The latter are rather concerned with "conflict-laden, emotionally charged fantasies and memories that are actively excluded from consciousness by the force of repression" (Riley and Postman, 1962). This defence mechanism, repression, thereby contributes to the unconscious regulation of potentially disturbing emotions. Suppression, on the other hand, is a similar process carried out voluntarily, with conscious awareness. The notion of perceptual defence (McGinnies, 1949) provides an example in the study of "repression". In short, the common paradigm of the corresponding studies consisted of very brief presentations of printed words to the subjects, using a tachyscope. Results showed that, obscene words had to be flashed for a longer duration to be identified than did neutral or positive words; this difference was interpreted as implying an unconscious perceptual defence. However, later research sought to explain such "defence" in more simplistic ways by appealing to effects such as words' frequency in a language (Hassin et al., 2005). Taken together, these and earlier studies have greatly influenced current experimental research on subliminal information processing.

In experimental settings, increasing effort has been directed to the investigation of the scope and limits of unconscious processing, with new methods sought to restrict conscious perception of a visual stimulus (Kim and Blake, 2005). Studies carried out in a limited number of patients with "blindsight" after brain damage (de Gelder et al., 2005; Hamm et al., 2003; Pegna et al., 2005) and studies using a backward-masking procedure (Carlsson et al., 2004; Rauch et al., 2000; Whalen et al., 1998) have gathered evidence that some visual-stimulus features of biological significance (e.g., emotional faces) are processed subcortically, triggering a fear response without conscious awareness (Adolphs, 2008; Killgore and Yurgelun-Todd, 2004; Ohman, 2002). Accordingly, it is hypothesised that a subcortical pathway through the superior colliculus and pulvinar to the amygdala can evaluate biologically relevant stimuli in a rapid but superficial way, functioning as an "alarm system" that can trigger a stress response. Aside from this pathway, there also exists a relatively longer "high road" which, through a series of higher-order cortical processing, provides a more elaborate analysis of stimuli. Crucially, it involves explicit operations within the cortex that are accessible through conscious attention (Killgore and Yurgelun-Todd, 2004; Pessoa and Adolphs, 2010). However, findings of more recent studies using continuous flash suppression (CFS) have challenged this viewpoint (Tsuchiya and Koch, 2005).

CFS is a relatively new methodology that has been widely adopted to investigate processing of visual stimuli outside of awareness. During CFS, one eye views rapidly flashing high-contrast dynamic patterns, rendering the stationary target stimulus presented to the other eye consciously invisible for periods of up to dozens of seconds (Yang et al., 2014). Therefore, it allows for a sufficiently large time-window for subliminal stimuli to be processed (Sklar et al., 2012). CFS also offers several other advantages over the previous methods for studying unconscious visual processing, such as complete suppression from consciousness (unlike backward masking) and an improved control of timing (unlike binocular rivalry) (Kim and Blake, 2005).

In contrast to the hypothesis that visual unconscious processing is limited by the activity of a subcortical route that solely processes basic visual information, previous research using this novel method provided evidence that the limits of the unconscious mind extend from biologically relevant to more complex information processing. For example, suppressed erotic images can either attract or repel observers' spatial attention depending on their gender and sexual orientation (Jiang et al., 2006). Compared to neutral words, emotionally descriptive and emotion-inducing negative words require a relatively long time for release from suppression (Yang and Yeh, 2011), with familiar words requiring less time (Jiang et al., 2007). Consciously invisible words have also been shown to be influenced by the semantic and subword priming effect (Costello et al., 2009).

1.3. Objectives and hypotheses

The extent to which emotional information of a rather complex visual stimulus can be processed in the absence of conscious perception remains controversial. Furthermore, the possible role of conscious cognitive processes on the regulation of such emotional responses is unclear. Our study attempted to provide some clarity to these concepts through three distinct experiments with methodologies of gradually increasing complexity.

In Experiment 1, we first tested the sensitivity of a relatively new methodology (0.1-Hz HRV index used together with 0.1-Hz stimulus presentation) reported to be an objective and sensitive means to detect the strength of autonomic reaction and regulation activity elicited by overtly presented affective pictures (Vaschillo et al., 2008). As indicated by a previous pilot study on the adequate experimental set-up for our purposes, we also attempted to improve the sensitivity of the 0.1-Hz HRV index, by additionally calculating its normalized value, given that the experimental procedure consisted of short-term HRV recordings. Although the experimental design was specifically built on the 0.1-Hz HRV methodology, we also included three traditional HRV indices (SDNN and pNN50 in the time domain, and LF/HF in the frequency domain) to compare their sensitivity in discriminating negatively valenced stimuli to the sensitivity of the 0.1-Hz HRV index. Second, we assessed whether the implementation of distancing technique, which is a relatively less studied form of cognitive reappraisal, enhanced the effectiveness of emotion regulation activity (Ochsner and Gross, 2005) by using this psychophysiological parameter.

Therefore, our first hypothesis in Experiment 1 was that the 0.1-Hz HRV index, together with its normalized value (predicted to be at least equally sensitive), would discriminate intra-individual changes in arousal and sensitively reflect the emotional regulation activity elicited by negative affective pictures. In other words, for both indices, the change scores over baseline in response to negative stimuli were expected to be greater compared to neutrals. We also predicted that the 0.1-Hz HRV indices would be significantly more sensitive than the traditional parameters to the negative valence. Our second hypothesis was that in the group using the distancing technique, the emotional responses elicited by negative affective cues would be more effectively regulated than those in the control group, and that this difference would be reflected by the change scores in the 0.1-Hz HRV indices (i.e.