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Review

Cardiac vagal control as a marker of emotion regulation in healthy adults: A review

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A B S T R A C T

In the last two decades, a growing body of theory and research has targeted the role of cardiac vagal control (CVC) in emotional responding. This research has either focused on resting CVC (also denoted as cardiac vagal tone) or phasic changes in CVC (also denoted as vagal reactivity) in response to affective stimuli. The present paper is aimed at reporting a review of the papers published between 1996 and 2016, and focused on the results of 135 papers examining cardiac vagal control as a physiological marker of emotion regulation in healthy adults. The review shows that studies have employed a wide array of methodologies and measures, often leading to conflicting results. High resting CVC has been associated with better down-regulation of negative affect, use of adaptive regulatory strategies, and more flexible emotional responding. Concerning phasic changes, research has consistently found decreased CVC in response to stress, while CVC increases have been shown to reflect either self-regulatory efforts or recovery from stress. Despite conflicting results, we conclude that existing literature supports the use of CVC as a noninvasive, objective marker of emotion regulation.

1. Introduction

Emotion regulation (ER) has been defined as the individual's ability to modulate the experience and expression of positive and negative emotions in accordance with the situational context where they unfold (Gross, 2001; Gross & Thompson, 2007). ER is thought to be critical for the individual's psychological functioning, as well as for overall adaptation to the physical and social environment (Gross & Munoz, 1995; Gross, 2007). For instance, effective ER has been shown to predict satisfactory social relationships (English, John, & Gross, 2013) as well as enhanced psychological well-being (Balzarotti, Biassoni, Villani, Prunas, & Velotti, 2016; Gross & John, 2003; Haga, Kraft, & Corby, 2009), while problems in emotion regulation have been linked to the development of psychopathological symptoms and emotional disorders (e.g., Gross & Munoz, 1995; Sheppes, Suri, & Gross, 2015).

Extensive psychophysiology research has focused on identifying biomarkers of emotion regulation – changes in physiological activation represent in fact a main emotional response domain (e.g., Levenson, 2003; for a review see Kreibig, 2010; Mauss & Robinson, 2009). In the past two decades, a growing number of studies has stressed the role of *cardiac vagal control* (CVC), which refers to the influence of the parasympathetic nervous system (PNS) on cardiac chronotropy through the vagus nerve (Grossman, Wilhelm, & Spoerle, 2004; Kimhy et al., 2013; Spangler & Friedman, 2015; Werner et al., 2015). CVC has been typically measured analyzing heart rate variability (HRV, defined as the variation in the time interval between heartbeats; Berntson, Eckberg, Grossman, Kaufmann, & Malik, 1997; Task Force of the European Society of Cardiology, 1996) and is thought to mark flexible regulation of autonomic arousal in line with situational demands (Appelhans & Luecken, 2006).

In the next paragraphs, a brief theoretical introduction on emotion regulation is given followed by an overview of the main theories that have been proposed to account for the relationship between CVC and emotional responding. Next, we provide a review of the empirical findings from 135 research studies examining CVC as a marker of emotion regulation.

2. A few hints on emotion, emotion regulation, and related constructs

Despite the existence of several divergent theoretical perspectives and a long-lasting scientific debate about how emotion should be defined (e.g., Gross & Barrett, 2011), there is general agreement among theorists in the field of affective science that emotions are multi-faceted, whole-body phenomena involving changes in the domains of expressive behavior, subjective experience (feelings), central and

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peripheral physiology. Also, most theories posit that emotions arise in response to stimuli/events that are evaluated as meaningful and relevant to the individual's goals (Gross & Thompson, 2007; Scherer, 2005). To explain differences among emotional states, some researchers have conceptualized emotions in terms of discrete categories, such as basic emotions (e.g., fear, anger, disgust; Ekman, 1992; Izard, 1992); by contrast, other researchers have privileged a dimensional approach, conceptualizing emotions in terms of broader dimensions underlying affective experience, such as hedonic valence (pleasant-unpleasant) and arousal (e.g. Russell, 2003; Watson, Clark, & Tellegen, 1988; for a review see Hamann, 2012).

Notably, emotions have been distinguished from other related affective processes (e.g., Gross, 1998; Gross & Thompson, 2007; Scherer, 2005). For instance, *stress* has been defined as an affective response to events that are appraised by the individuals as taxing or exceeding their resources and/or threatening their wellbeing (Lazarus & Folkman, 1984; Lazarus, 1966). *Moods* differ from emotions as they generally denote diffuse affective states, characterized by a relative enduring prevalence of positive or negative feelings; moods have longer duration than emotions and are less likely to be tied to specific events (Beedie, Terry, & Lane, 2005; Parkinson, Totterdell, Briner, & Reynolds, 1996). *Affective dispositions* consist of emotion-linked personality traits describing the tendency of an individual to experience certain moods more often, or his or her proneness to react with certain types of emotions (Scherer, 2005). Finally, although 'emotion' and '*affect*' are often interchangeably used, it has been suggested to conceive this latter as a superordinate category for various kinds of (positively vs. negatively) valenced states (Gross & Thompson, 2007; Scherer, 1984).

Emotion regulation (ER) concerns the way people manage their emotions and has been defined as comprising all the conscious and unconscious strategies individuals use to reduce (*down-regulation*), maintain, or increase (*up-regulation*) either positive or negative emotions (Gross, 2001). In the past two decades, there has been a dramatic increase in research on ER and a considerable debate has emerged on this construct (e.g., Kappas, 2011; Gross, Sheppes, & Urry, 2011; Mesquita & Frijda, 2011; for a review see Koole, 2009).

Among the most prominent models of ER, the process model (Gross, 1998, 2001, 2007, 2015; Gross & Thompson, 2007) provides a conceptual framework to organize the myriad forms of ER that people use and to explain how these forms differ in their affective, cognitive, and social consequences. The model differentiates two major kinds of ER on the basis of how emotions unfold over time (Gross, 2001, 2015). A*ntecedent-focused* strategies intervene early in the emotion generation process, before the complete activation of emotion response tendencies: This group of strategies includes situation selection and modification, attentional deployment (e.g., distraction), and cognitive change (e.g., cognitive reappraisal, defined as the attempt to reinterpret a situation's meaning in a way that alters its emotional impact). Conversely, *response-focused* strategies occur late in the emotion generation process (once an emotion has been fully generated) and, for this reason, are hypothesized to require more efforts to manage emotional responses as they continually arise, taxing the individual's resources. This second group includes strategies that alter expressive, physiological, or behavioral responding as directly as possible (e.g., emotional suppression, defined as the attempt to inhibit the outward display of emotions).

Within the theoretical framework provided by Gross' process model, ER strategies – most commonly, cognitive reappraisal as typical of antecedent-focused and suppression as representative of response-focused strategies – have been studied in two different forms. Experimental research has targeted instructed use, for instance asking participants to reappraise emotional stimuli such as unpleasant clips or images. Correlational studies have assessed spontaneous use (i.e., the frequency with which individuals habitually use a certain strategy), conceptualizing ER strategies as trait-level individual difference variables (Gross & John, 2003). Consistent with theoretical predictions, extensive research has found that reappraisal and suppression have different implications for the individual's psychological functioning (for a review, see Cutuli, 2015; Gross, 2015). Briefly, research has shown that instructed reappraisal is more effective at down-regulating many aspects (e.g., subjective feeling, physiological arousal) of negative emotional responding than suppression. Also, suppression but not reappraisal has been shown to lead to adverse cognitive (e.g., worse memory) and social (e.g., reduced responsiveness) consequences. Likewise, habitual use of reappraisal has been associated with greater experience of positive and lesser experience of negative affect, as well as with higher psychological wellbeing (Gross & John, 2003; McRae, Jacobs, Ray, John, & Gross, 2012). By contrast, habitual suppression has been related to higher negative affect, lower well-being, and impaired social functioning (Gross & John, 2003; English et al., 2013).

Paralleling the distinction between emotion and other affective processes, ER has been distinguished from other related forms of affect regulation (Gross & Thompson, 2007). For instance, a long-lasting research tradition has focused on *coping*, defined as the individual's cognitive and behavioral efforts to manage events or situations that are appraised as taxing or exceeding his or her resources (e.g., Lazarus & Folkman, 1984). A wide number of studies have examined individual differences in the use of coping strategies, differentiating between problem-focused vs. emotion-focused, engagement vs. disengagement, primary vs. secondary coping strategies (Carver, Scheier, & Weintraub, 1989; Lazarus & Folkman, 1984; for a review, see Skinner, Edge, Altmen, & Sherwood, 2003). Although closely related, coping has been distinguished from ER by its primary emphasis on reducing stress (Gross, 2015). Along with this line, correlational studies have shown that habitual use of ER strategies is only moderately correlated with the use of coping strategies, as well as with broader emotion-linked personality traits, such as neuroticism and extraversion (Gross & John, 2003).

Recently, the extended model of ER (Todd, Cunningham, Anderson, & Thompson, 2012) has stressed the role of attentional processes, as part of the interplay between cognitive and emotional processes in ER. The model differentiates among ER strategies depending on whether they modulate emotional responses before or after the occurrence of an emotional event, as well as on the amount of cognitive effort that they require (reflexive vs. effortful strategies). In this view, *affect-biased attention* – defined as the tendency to attend to affectively salient stimuli over others – is thought as a rapid, reflexive process of filtering (based on one's past experience), which acts prior to the occurrence of an emotional event (e.g., by biasing perception towards particular types of positive or negative stimuli). Since it influences subsequent emotional responses, affect-biased attention is conceived as a critical component of ER.

3. Theoretical foundations: why CVC may be a relevant marker of ER

Two prominent models have been proposed to describe neural pathways connecting the brain and the heart and provide a framework for conceptualizing CVC as a marker of emotion regulation (and of self-regulation more in general): Porges' polyvagal theory (Porges, 2007; Porges, Doussard-Roosevelt, Portales, & Greenspan, 1996) and Thayer's model of neurovisceral integration (Thayer & Friedman, 2002; Thayer & Lane, 2000, 2009).

Briefly, the polyvagal theory (Porges, 1995, 1997, 2001, 2003, 2007) is based within an evolutionary framework and suggests that the neural circuits involved in the regulation of the organism's autonomic state evolved to support adaptive responses to safe or threatening life contexts, as well as mammals' social behavior. The core idea underlying the polyvagal theory is that the vagus complex functions as a 'brake': It actively inhibits the influence of the sympathetic nervous system (SNS) on heart activity and reduces the stress response of the hypothalamic-pituitary-adrenal axis (HPA), allowing states of calmness that are necessary to engage in social behaviors. At rest, when the environment is perceived as stable and safe, the vagal brake slows the heart, facilitating general attention to the environment, relaxation, as well as social engagement behaviors. This braking process is reflected by increases in measures of CVC. By contrast, in stressful situations, the vagal brake is quickly reduced to support rapid mobilization of metabolic resources that are necessary to prepare for appropriate action (e.g., fight or flight response). This vagal withdrawal is reflected by decreases in measures of CVC.

The model of neurovisceral integration (Thayer & Lane, 2000, 2009; Thayer, Åhs, Fredrikson, & Wager, 2012) conceives heart rate variability as the output deriving from the activity of a network of brain structures (the so called central autonomic network, CAN; Benarroch, 1993) which remotely regulates the interplay of sympathetic and parasympathetic influences on the heart. The neurovisceral theory describes a common reciprocal inhibitory neural circuit associated with self-regulation processes in which subcortical structures underpinning defensive behavior (e.g., the amygdala) are under tonic inhibitory control of prefrontal cortical regions (Thayer & Brosschot, 2005; Thayer & Lane, 2009). In case of threat or stress, the prefrontal cortex becomes hypoactive, leading to parasympathetic withdrawal and disinhibition of the sympathoexcitatory circuits that activate the organism to respond to the threatening event. The neurovisceral theory emphasizes the importance of inhibitory neural circuits for goal-directed behavior and flexible responsiveness to situational demands: The disruption of these inhibitory processes may result in hyperactivity, defensiveness, perseveration, and rigidity. Measures of CVC are thus proposed to reflect ER – as well as executive control functions more in general – because they are peripheral markers of prefrontal cortex inhibitory activity (Beauchaine, 2015).

Overall, both the polyvagal and the neurovisceral theories conceive CVC as a marker of autonomic flexibility, defined as the dynamic adjustment of the levels of physiological arousal in line with contextual demands (Appelhans & Luecken, 2006; Friedman, 2007; Friedman & Thayer, 1998). The vagal brake represents a neural mechanism to rapidly adjust physiological states by slowing down or speeding up heart rate (Porges, 1995, 2001; Porges et al., 1996). Likewise, the neurovisceral integration model conceives vagal regulation of heart rate as a marker of prefrontal control on subcortical activity, which results in effective functioning of self-regulatory systems (Thayer & Lane, 2000; Thayer, Hansen, Saus-Rose, & Johnsen, 2009).

4. Quantifying CVC: resting and phasic measures of respiration-linked HRV

When examining the relationship between CVC and emotion regulation, researchers have either focused on '*resting*' CVC or '*phasic*' changes in CVC in response to affective stimuli/events. Resting CVC reflects individual (i.e., between-subject) differences in tonic vagal control of heart rate (Berntson et al., 1997), which has been often denoted as *vagal tone* or *cardiac vagal tone* (CVT; e.g., Miskovic & Schmidt, 2010; Kogan, Gruber, Shallcross, Ford, & Mauss, 2013; Souza et al., 2007). Measures of resting CVC are commonly obtained during either a paced breathing task (e.g., Butler, Wilhelm, & Gross, 2006; Volokhov & Demaree, 2010) or a baseline period asking subjects to relax and breath normally (e.g., Cribbet, Williams, Gunn, & Rau, 2011). Conversely, phasic (within-subject) changes in CVC concern variations from rest to a stress or challenging situation (often denoted as *vagal reactivity*), as well as variations to restore baseline CVC levels after stress (often denoted as *vagal recovery*).

According the theories presented above, autonomic flexibility is thought to correspond to high levels of resting CVC (i.e., robust tonic vagal regulation of heart rate). Concerning phasic regulation, temporarily decreased CVC in case of stress or challenge (also referred to as *vagal withdrawal* or *vagal suppression*), as well as fast subsequent recovery should reflect reactivity of the PNS and are thus considered as adaptive responses to stressors (Movius & Allen, 2005; Porges, 1992; Friedman, 2007).

To quantify (either resting or phasic) CVC, investigators have relied on estimates of respiration-linked HRV, as there is evidence that variations in heart rate (HR) associated with the breathing cycle are predominantly vagally controlled (e.g., McCabe, Youngue, Ackles, & Porges, 1985). Respiration-linked HRV is often denoted as *respiratory sinus arrhythmia* (RSA), a physiological phenomenon consisting in the periodic increases and decreases in HR that occur during inspiration and expiration respectively (e.g., Berntson et al., 1997; Grossman & Kollai, 1993; Ritz, 2009; for concerns and caveats regarding the use of RSA as an index of CVC, see Grossman & Taylor, 2007).

RSA, however, can be quantified in several different ways – commonly researchers have used power spectral analysis of heart rate in the high frequency (HF) band. Although a detailed discussion about RSA metrics is beyond the scope of this review (see Allen, Chambers, & Towers, 2007; Denver, Reed, & Porges, 2007; Grossman, van Beek, & Wientjes, 1990; Lewis, Furman, McCool, & Porges, 2012), it is important to note that no consensus among investigators has yet emerged on a single optimal method; the selection of RSA metrics is highly variable across studies (Allen et al., 2007).

5. Method

Peer-reviewed studies published between 1996 and 2016 were located in PSYCHINFO with combinations of the following keywords: emotion; emotion regulation; stress* respiratory sinus arrhythmia; heart rate variability; HRV; cardiac vagal control; cardiac vagal tone; vagal; cardiac reactivity. In addition to this electronic search; the reference list of each relevant article was examined for additional studies. The year 1996 was selected as starting date thereby considering published research in last two decades; more dated studies have been examined by previous reviews (Appelhans & Luecken, 2006; Thayer & Lane, 2009).

The inclusion criteria were as follows. First, included studies employed estimates of respiration-linked HRV (or RSA) calculated using time-domain measures (e.g., root mean square of square successive difference, RMSSD) and/or frequency-domain measures derived through spectral analysis (i.e., HRV in the high frequency band, HF-HRV). We reviewed both studies adjusting RSA estimates for respiration and studies not controlling for this variable (for a discussion of this issue, see Grossman & Taylor, 2007; Houtveen, Rietveld, & de Geus, 2002; Laborde, Mosley, & Thayer, 2017; Quintana & Heathers, 2014; Ritz, 2009). Details concerning metrics and method for quantification employed by the studies included in this review are provided in Tables S.1 and S.2 (Supplementary Materials). Metrics have been classified drawing from Allen et al. (2007).

Second, included studies employed a measure of emotion and/or emotion regulation and/or an emotional induction paradigm. Studies focusing on other facets of self-regulation such as cognitive control and executive functioning (e.g., Kimhy et al., 2013; Overbeek, van Boxtel, & Westerink, 2014; Thayer et al., 2009) were not considered. Third, included studies were conducted on samples of healthy adults and (fourth) were written in English.

The search returned 238 articles; however, the total number of studies was reduced to 135 after determining whether the study met inclusion criteria. Studies were excluded if the sample consisted of children and/or adolescents, as well as of groups of individuals with psychopathological symptoms (for reviews addressing the role of HRV in psychopathology, see Hamilton & Alloy, 2016; Thayer & Brosschot, 2005).

6. Results

6.1. Resting CVC as a marker of effective ER

Empirical evidence about resting CVC (CVC_{REST}) in healthy adults is controversial (Grossman & Taylor, 2007). Although research has tested the hypothesis of CVC_{REST} as a physiological marker of individual differences in ER, investigators have focused on different aspects of this multifaceted construct, as well as on other related forms of affect regulation. For this reason, we will review different lines of research by grouping together the studies that have focused on the relationship between CVC_{REST} and one of the following ER aspects: 1) the ability to flexibly orient attention towards affectively salient stimuli (Todd et al., 2012); 2) emotional reactivity (i.e., how strong one's emotional response is to affective vs. neutral stimuli or events); 3) spontaneous or instructed use of ER strategies; 4) emotion-linked personality traits and overall subjective well-being; 5) adaptive social functioning.

6.1.1. Modulation of emotional attention

The first line of research has examined the link between CVC_{REST} and the modulation of emotional attention, defined as the ability to flexibly orient attention towards emotionally salient stimuli. This research has predicted individuals with high CVC_{REST} to show more adaptive patterns of emotional attention relative to individuals with low CVC_{REST} (for a review, see Park & Thayer, 2014).

For instance, in one study asking participants to view emotional (pleasant, unpleasant) and neutral pictures with acoustic startle probe, high CVC_{REST} individuals showed startle potentiation to unpleasant and startle inhibition to pleasant images compared to the neutral ones, thereby exhibiting a clear differentiation among the presented foregrounds. By contrast, low CVC_{REST} individuals showed enhanced startle responses to neutral stimuli as if they were emotionally negative (Ruiz-Padial, Sollers, Vila, & Thayer, 2003). Similarly, Park, Moon, Kim, and Lee (2012) observed heightened neural responses during visual perception of both fearful and neutral stimuli in people with low CVC_{REST}, supporting the hypothesis of poor attentional regulation in individuals with low CVC_{REST}.

Other studies have shown that low CVC_{REST} is associated with attentional biases for affective stimuli. For instance, using an emotional spatial cueing task, Miskovic and Schmidt (2010) found that low CVC_{REST} was associated with biased attention to angry but not happy faces, suggesting an association of low CVC_{REST} with hypervigilance to social threatening stimuli. In a series of studies, Park, Van Basel, Vasey and Thayer (2013) observed that low CVC_{REST} individuals displayed faster attentional engagement to fearful stimuli when they were presented under automatic bottom-up attentional mode (indicating hypervigilance), as well as slower attentional disengagement from fearful faces when presented under voluntary top-down attentional mode (indicating a failure to inhibit attention to threatening stimuli). People with low CVC_{REST} have also been shown to be less accurate at discriminating between fearful and neutral faces than people with high CVC_{REST} (Park, Van Bavel, Egan, Vasey, & Thayer, 2012), less capable to inhibit attention from fearful distractors and initiate novelty search (Park, Van Bavel, Vasey, & Thayer, 2012), and less able to control selective attention in the presence of emotional distractors under high cognitive load (Park, Vasey, Van Bavel, & Thayer, 2013; Park, Van Bavel, Vasey, & Thayer, 2014).

Taking these findings together, it has been argued that low CVC_{REST} is associated with maladaptive patterns of attentional orienting – such as hyper-vigilant responses to unpleasant stimuli and inability to inhibit task-irrelevant distractors – that may impair ER (Park, Moon et al., 2012).

6.1.2. Emotional reactivity

The second line of studies concerns the relationship between CVC_{REST} and emotional responses (e.g., autonomic and neurophysiological correlates, facial behavior, self-report feelings) to a variety of affective stimuli (e.g., films, pictures, emotional tasks). This research has been informed by two distinct perspectives (Butler et al., 2006; Ode, Hilmert, Zielke, & Robinson, 2010). On the one hand, several studies have considered 'regulated' emotional responses as indexed by less negative and more positive emotional responding to stressful or challenging situations (*regulation* hypothesis). This research has generally predicted high CVC_{REST} individuals to react less negatively to unpleasant stimuli than low CVC_{REST} individuals (e.g., Appelhans & Luecken, 2008; Demaree, Robinson, Everhart, & Schmeichel, 2004; Demaree, Pu, Robinson, Schmeichel, & Everhart, 2006; Dywan, Mathewson, Choma, Rosenfeld, & Segalowitz, 2008; Palomba, Sarlo, Angrilli, Mini, & Stegagno, 2000; O'Connor, Gundel, McRae, & Lane, 2007; Del Ventura & Rhudy, 2012). By contrast, other studies have argued that – since high levels of CVC_{REST} mark physiological flexibility (Porges, 1997; Thayer & Lane, 2000) – CVC_{REST} should be associated with greater emotional reactivity, that is, greater intensity of the emotional response within the 'normal' range (Butler et al., 2006; Frazier, Strauss, & Steinhauer, 2004). In other words, individuals with high CVC_{REST} are expected to experience and express situationally appropriate emotional reactions (e.g., Fujimura & Okanoya, 2012; Geisler, Kubiak, Siewert, & Weber, 2013), rather than less negative emotions in general (*flexibility* hypothesis).

Consistently with the regulation hypothesis, some research has found CVC_{REST} to be negatively related to indices of emotional reactivity. For instance, in one study examining electrophysiological correlates (evoked potentials, ERPs) of negative affect in response to errors in a memory task, lower CVC_{REST} was associated with higher sadness and more pronounced amplitude of error-related ERPs (Dywan et al., 2008). Similarly, another study measuring brain activation (O'Connor et al., 2007) found that individuals with low CVC_{REST} reported more intense grief while viewing photos of deceased love ones paired with grief words, as well as greater activity in brain areas involved in autonomic arousal. Other studies have found low CVC_{REST} to be associated with fear-potentiated startle responses to threat (Melzig, Weike, Hamm, & Thayer, 2009), increased psychological distress when experiencing a high-stress period (Gouin, Deschênes, & Dugas, 2014), poor cardiovascular recovery from acute social stress (Diamond & Hicks, 2005; Souza et al., 2007), and higher instability of positive affect (Koval, Ogrinz, Kuppens, Van den Bergh, & Tuerlinckx, 2013). These findings suggest poor emotion regulation in individuals with low CVC_{REST}. Finally, in one study asking participants to read an anger-provoking story about an interpersonal offense (Léon et al., 2009), participants with high CVC_{REST} attributed significantly less other-blame, which in turn reduced their anger. By contrast, individuals with low CVC_{REST} were not able to make a calm evaluation of the scenario, increasing their perception of blame and consequently their feelings of anger.

On a related note, Dunn, Evans, Makarova, White, and Clark (2012) examined whether CVC_{REST} was associated with the rejection of unfair financial offers in the ultimatum game: Rejection behavior is in fact thought to reflect a failure in regulating anger/frustration elicited by perceived unfairness, which overrides an economic decision. On each trial, the proposer makes a once-only offer with no impact on reputation: The "rational" responder behavior would thus be to accept all offers, no matter how unfair, as neither player receives any money in case of rejection. The results showed that participants with low CVC_{REST} displayed higher rejection rates than participants with high CVC_{REST}, thus suggesting poorer regulation of negative emotion. Similarly, in one study examining the influence of the emotional outcome of a choice on subsequent decision making (Katahira, Fujimura, Matsuda, Okanoya, & Okada, 2014), negative outcomes (i.e., unpleasant pictures) induced stronger avoidance behavior in subsequent choices for participants with low CVC_{REST} than for participants with high CVC_{REST} (i.e., low CVC_{REST} participants were more susceptible to negative outcomes and less able to control the influence of negative emotion on their decisions).

Several studies, however, have found contradictory results across different indices of emotional response. In a series of experimental studies, Demaree and colleagues (Demaree et al., 2004, 2006; Pu, Schmeichel, & Demaree, 2010; Volokhov & Demaree, 2010) found that individuals with high CVC_{REST} displayed less negative facial behavior when naturally watching a disgusting film (Demaree et al., 2004, 2006). Individual differences in CVC_{REST}, however, did not impact negative emotional experience, as participants with higher CVC_{REST}

expressed less but reported feeling just as much negative emotion as those with lower CVC_{REST} (Pu et al., 2010). Also, CVC_{REST} was not related to indices of autonomic responding (i.e., participants with high and low CVC_{REST} showed similar levels of physiological arousal; Demaree et al., 2004; Demaree et al., 2006; Pu et al., 2010; Volokhov & Demaree, 2010). Likewise, Dufey, Hurtado, Fernández, Manes, & Ibáñez (2011) detected significant differences between participants with high vs. low CVC_{REST} in several ERP components reflecting emotional processing of affective pictures; however, participants reported comparable subjective ratings of both valence and arousal. Other studies have found low CVC_{REST} people to exhibit attenuated cardiac orienting (i.e., smaller HR decreases) in response to unpleasant pictures compared to high CVC_{REST} participants (Palomba et al., 2000; Ventura & Rhudy, 2012), but no significant differences emerged in a wide range of emotion measures (i.e., subjective feelings, facial behavior, startle response, and indices of autonomic activity other than HR).

Notably, contradictory results have been found regarding valence. While some studies have shown differences between high vs. low CVC_{REST} individuals in indices of negative but not positive emotional reactivity (e.g., Demaree et al., 2004, 2006; Katahira et al., 2014), other studies have found the reverse pattern (e.g., Fujimura & Okanoya, 2012; Koval et al., 2013).

To account for these inconsistent results, some research has advanced the *flexibility* hypothesis, predicting that CVC_{REST} would be associated with more intense emotional responses that are appropriate to the eliciting situation.

Consistent with this view, high CVC_{REST} was found to predict greater variability and intensity of positive and negative emotions when responding to the Rorschach test (Kettunen, Ravaja, Naatanen, & Keltikangas-Jarvinen, 2000), suggesting that individuals with relatively high levels of CVC_{REST} are emotionally more responsive. Along with this line, high CVC_{REST} was associated with increased salivary cortisol (i.e., a physiological response to stress) while performing stressful laboratory tasks (Smeets, 2010). Another study employing a social task (i.e., pairs of women discussing about an upsetting topic; Butler et al., 2006), showed that participants with high CVC_{REST} reported greater negative experience and expressed more negative but less positive emotion during the conversation than participants with low CVC_{REST} – coherently with the topic being discussed, that is, the atrocities of Hiroshima and Nagasaki. In a diary study asking participants to reflect on their emotional and social experiences each day for nine weeks, Kok and Fredrickson (2010) found that high CVC_{REST} predicted more rapid increases in positive emotions, but was also associated with higher levels of negative emotions throughout the nine weeks. Likewise, CVC_{REST} was shown to be a positive predictor of the number of daily episodes of sadness and anger reported over a month (Geisler et al., 2013).

However, other studies have failed to confirm the flexibility hypothesis. For instance, no associations were found between CVC_{REST} and emotional responses (either in the experiential, expressive, or physiological response systems) to a wide range of negative and positive films (Frazier et al., 2004). Likewise, CVC_{REST} did not predict significant increases of positive (or negative) emotions in response to compassion-, awe-, or pride-inducing pictures (Oveis et al., 2009), or while recalling a recent stressful event (Cribbet et al., 2011).

Overall, both the regulation and flexibility perspectives have yielded contradictory results. Research informed by the regulation hypothesis seems to suggest that low CVC_{REST} individuals tend to exhibit heightened negative emotional reactivity, even though several studies have found inconsistencies across different indices of emotional response.

6.1.3. Emotion regulation strategies

The third line of research has examined the association between CVC_{REST} and the (either spontaneous or instructed) use of ER and coping strategies.

For instance, some studies have found individuals with high CVC_{REST} to be more effective at regulating facial behavior under regulatory instructions to exaggerate their emotional response (Demaree et al., 2004), to report higher spontaneous use of cognitive reappraisal and emotional suppression when viewing an unpleasant film (Volokhov & Demaree, 2010), as well as lower spontaneous use of avoidance in response to disgusting-provoking pictures than individuals with low CVC_{REST} (Aldao, Dixon-Gordon, & De Los Reyes, 2016). Other related evidence comes from studies finding positive associations of CVC_{REST} with the ability to persist in a difficult task (Segerstrom & Solberg Nes, 2007), with self-control after a failure (Geisler & Kubiak, 2009), effortful control (Spangler & Friedman, 2015), and self-reported attentional control (Balle et al., 2013). Notably, CVC_{REST} has been also shown to moderate the affective consequences of the use of regulatory strategies: In one study asking romantic couples to discuss a topic of conflict (Geisler & Schröder-Abé, 2015), spontaneous use of suppression was associated with higher experience of negative affect in partners with low CVC_{REST}, while it was related to greater relationship satisfaction and conflict resolution in partners with high CVC_{REST}.

Similarly, correlational research has revealed significant associations of CVC_{REST} with self-report measures of regulatory and coping strategies (Fabes & Eisenberg, 1997; O'Connor et al., 2002; Geisler et al., 2013; Martin et al., 2011; Ramaekers, Ector, Demyttenaere, Rubens, & Van de Werf, 1998). For instance, CVC_{REST} was shown to be positively associated with self-report measures of regulatory control, as well as with the daily use of constructive coping strategies in response to daily life highly stressful events (Fabes & Eisenberg, 1997). Along with this line, high CVC_{REST} was found to predict greater use of engagement coping in response to stressors (Geisler et al., 2013; Study 1), lower use of avoidance and disengagement coping strategies in response to daily negative emotions (i.e., anger and sadness; Geisler et al., 2013; Study 2), as well as less use of passive coping strategies (and lower levels of depression) in a group of bereaved individuals (O'Connor, Allen, & Kaszniak, 2002). In another study (Geisler, Vennewald, Kubiak, & Weber, 2010), high CVC_{REST} was found to be associated with the habitual use of executive ER strategies (e.g., reappraisal or refocusing), which in turn mediated the positive relationship between CVC_{REST} and subjective well-being (as indexed by positive hedonic tone, calmness, and satisfaction with life).

A few studies have found that people with high CVC_{REST} display better outcomes after being exposed to emotion-related interventions than people with lower CVC_{REST}, indicating that high CVC_{REST} may reflect greater abilities of self-soothing and emotion regulation. For instance, bereaved participants with higher levels of CVC_{REST} were shown to benefit from written disclosure more than bereaved participants with lower levels of CVC_{REST} (O'Connor, Allen, & Kaszniak, 2005). Similarly, Sloan and Epstein (2005) found that healthy students with higher levels of CVC_{REST} benefited most from written disclosure about traumatic experiences concerning depression symptoms and physical health complaints. Finally, CVC_{REST} was found to interact with type of intervention (a training focused on meditation vs. a control waiting list) to predict the degree of success people had in self-generating positive emotions, so that participants with high CVC_{REST} showed sharper increases in positive emotions over the course of the training than participants with CVC_{REST} (Kok et al., 2013).

Although the studies we reviewed so far consistently suggest an association between CVC_{REST} and the use of ER and coping strategies, some research has found less empirical support for this relationship (e.g., Ramaekers et al., 1998), with some studies failing to find significant associations (Berna, Ott, & Nandrino, 2014; Koval et al., 2013; Laborde, Lautenbach, & Allen, 2015). For instance, Ramaekers et al. (1998) found that CVC_{REST} was positively associated with venting of negative emotion but not with active coping, and this association was significant for middle-aged men only. In a one-week diary study (Koval et al., 2013), CVC_{REST} was not significantly related to trait measures of either cognitive reappraisal or emotional suppression.

6.1.4. Emotion-linked personality traits and subjective well-being

The fourth line of research has examined cross-sectional associations of CVC_{REST} with emotion-linked personality traits, as well as with overall subjective well-being.

A number of studies have shown high CVC_{REST} to be related to trait positive emotion as indexed by extraversion, agreeableness, disposition toward optimism, and positive mood (Oveis et al., 2009), positive affect and positive expressivity (Wang, Lü, & Qin, 2013), self-esteem (Martens et al., 2010; Schwerdtfeger & Scheel, 2012), and measures of subjective well-being (e.g., satisfaction with life; Laborde et al., 2015). Conversely, CVC_{REST} has been negatively associated with measures of trait negative emotion such as neuroticism (Oveis et al., 2009), trait worry (Knepp, Krafka, & Druzina, 2015), defensiveness (Dikman, Allen, & Movius, 2001), anxiety, depressive symptoms, and perceived stress (Muhtadie, Koslov, Akinola, & Mendes, 2015). In a diary study asking participants to daily report about problematic outcomes (e.g., stress, negative emotions, and somatic symptoms, Ode et al., 2010), individual differences in CVC_{REST} were not related either to neuroticism (which reflects predisposition towards negative affect; Clark & Watson, 1999) or to any of the multiple problematic indices. Nevertheless, the results pointed to an interactive pattern in which neuroticism was a predictor of more problematic daily outcomes at low but not at high levels of CVC_{REST}.

Finally, a recent study (Kogan et al., 2013) has found evidence of quadratic rather than linear relationships between CVC_{REST} and various measures of subjective well-being (i.e., life satisfaction, habitual mood, global functioning, and depressive symptoms), reflecting an increase in well-being as CVC_{REST} increased and then a decline. Based on this finding, it has been suggested that the relationship between CVC_{REST} and positive psychological functioning might be nonlinear, with an 'optimal' level of CVC_{REST} in the moderate to-high range. Recent research testing the robustness of this association across multiple HRV metrics (Silvia, Jackson, & Sopko, 2014), however, has returned inconsistent results. Small non-significant associations (either linear or quadratic) were found between CVC_{REST} and personality traits (neuroticism, extraversion, agreeableness, openness to experience, conscientiousness), dispositional positive emotions, and depressive symptoms.

6.1.5. Social functioning

Finally, the fifth line of research has predicted CVC_{REST} to be positively related to the quality of social relationships. Capacities for affect regulation are in fact thought to play a crucial role for adaptive interpersonal functioning: Social interactions can induce intense emotional reactions, thereby demanding extensive regulatory efforts (e.g., Butler et al., 2006; Keltner & Kring, 1998).

Consistently with this view, some studies have found CVC_{REST} to be positively associated with self-report measures of adaptive social functioning (for an exception, see Egizio et al., 2008), such as social integration and social acceptance (Geisler et al., 2013; Study 1), marital quality (Smith et al., 2011), social connectedness (Kok & Fredrickson, 2010; Kok et al., 2013), and secure attachment (Diamond & Hicks, 2005). Moreover, in a 3-week diary study on cohabiting couples, high CVC_{REST} was related to better quality of day-to day couples' interactions and positive daily affect (Diamond, Hicks, & Otter-Henderson, 2011). In a recent study (Kogan et al., 2014), CVC_{REST} was a significant positive predictor of agreeableness and warm social relationships with others (Study 1), experience of prosocial positive emotions (compassion and gratitude; Study 2), as well as of judgments of prosociality expressed by strangers who observed the participants' nonverbal behavior while listening to their partner's stories about an episode of emotional suffering (Study 3). This study, however, found evidence of non-linear (inverted-U) relationships, thus suggesting that too high (extreme) CVC_{REST} levels may become maladaptive.

A second group of studies has examined whether CVC_{REST} is predictive of better ability to employ and recognize social cues (Côté et al., 2011; Quintana, Guastella, Outhred, Hickie, & Kemp, 2012; Tuck, Grant, Sollers, Booth, & Consedine, 2016). Participants with higher CVC_{REST} have been found to be more accurate at expressing anger than participants with lower CVC_{REST} (even though no differences emerged in the expressive accuracy of other emotions such as fear, joy, and disgust; Tuck et al., 2016). Similarly, CVC_{REST} was found to positively correlate to empathic accuracy in face-to-face interactions (Côté et al., 2011), as well as to the ability of emotion recognition (Quintana et al., 2012).

Finally, a few studies have considered the relationship between CVC_{REST} and negative social behavior, such as hostility and aggression. In one study examining emotional control and hostility behavior in conflicts with romantic partners (Gyurak & Ayduk, 2008), CVC_{REST} was found to buffer against rejection sensitivity (i.e., trait proneness to aggressive behavior in relationship conflicts): Highly rejection-sensitive individuals reported less emotion control and more hostility in conflicts only if they were also low in CVC_{REST}. Unexpectedly, however, CVC_{REST} was positively related to hostility behavior in low rejection-sensitive individuals. Similarly, a recent study (Zhang & Gao, 2015) has found a positive association between CVC_{REST} and reactive aggression in conditions of high (but not low) social adversity.

6.1.6. Summary: regulation vs. flexibility

The number of studies linking CVC_{REST} and emotion regulation has recently grown. Although research and theory support the utility of CVC_{REST} as a noninvasive, objective marker of individual differences in emotion regulatory capacity, existing evidence is mixed and does not convey a clear picture.

Overall, researchers have been informed by two distinct ways of conceptualizing CVC_{REST} as a marker of 'adaptive' ER. On the one side, the majority of studies have searched for positive associations between CVC_{REST} and down-regulation of negative affect, adaptive coping strategies, trait positive emotion (e.g., optimism and positive mood), subjective well-being, and adaptive social functioning (the regulation hypothesis). Despite conflicting evidence, the studies reviewed above seem to point to four main findings that are consistent with this view. First, low CVC_{REST} individuals tend to exhibit hypervigilance to negative stimuli (e.g., Miskovic & Schmidt, 2010), as well as heightened negative emotional reactivity (e.g., Dywan et al., 2008; Dunn et al., 2012; Gouin et al., 2014; Katahira et al., 2014; Léon, Hernández, Rodríguez, & Vila, 2009; Melzig et al., 2009; O'Connor et al., 2007), possibly suggesting poor down-regulation of negative affect. Second, a number of studies have shown high CVC_{REST} to be related to greater use of adaptive and lower use of maladaptive ER/coping strategies (Aldao et al., 2016; Geisler et al., 2010; Geisler et al., 2013; O'Connor et al., 2002), as well as to higher positive and lower negative emotion-linked personality traits (Oveis et al., 2009; Muhtadie et al., 2015; Wang et al., 2013). Third, a few studies have demonstrated that high CVC_{REST} may exert a buffering effect against maladaptive traits (Geisler & Schröder-Abé, 2015; Gyurak & Ayduk,2008; Martin et al., 2011). Finally, CVC_{REST} has shown positive associations with measures of adaptive social functioning (e.g., Diamond et al., 2011; Smith et al., 2011).

Other researchers, however, have argued that CVC_{REST} should be considered as a correlate of flexible patterns of emotional responding, thus conceiving ER as the ability to flexibly adapt one's behavior to the situation/stimulus (e.g., Butler et al., 2006; Fujmura & Okanoya, 2012; Ode et al., 2010). This perspective refers to the evidence that low CVC_{REST} individuals' responses are characterized by rigidity, as indexed by inability to flexibly orient attention away from negative task-irrelevant stimuli (Park, Van Bavel, Vasey et al., 2012; Park, Vasey, Van Bavel, & Thayer, 2013), exaggerated defensive responses (e.g., enhanced startle, hyper-arousal) to neutral and positive (i.e., non-threat) stimuli (Fujmura & Okanoya, 2012; Ruiz-Padial et al., 2003), and pronounced autonomic stress responses to trivial emotionally-negative distractors (Park, Van Bavel et al., 2014; Park, Lee et al., 2014). There is also evidence that high CVC_{REST} can be associated with intense negative emotional responding coherently with the eliciting situation (Butler et al., 2006; Gyurak & Ayduk, 2008; Geisler et al., 2013).

Contrasting both the regulation and the flexibility perspectives, however, we also found some evidence suggesting that no significant associations may exist between CVC_{REST} and indices of emotion regulation (e.g., Frazier et al., 2004; Silvia et al., 2014). Notably, a recent meta-analysis examining the link between CVC_{REST} and self-control in laboratory tasks (Zahn et al., 2016) has found evidence of a small association, which was no longer significant after controlling for publication bias.

6.2.1. Phasic changes in CVC

Various authors have argued that resting and phasic measures of CVC are differentially related to emotional processes and are thus not redundant (e.g., Butler et al., 2006; Frazier et al., 2004; Movius & Allen, 2005). However, while CVC_{REST} is conceived to mark trait-like, individual differences in self-regulation abilities, there is less agreement about what phasic regulation of CVC (CVC_{PHA}) may represent. Some studies have examined whether transient CVC_{PHA} changes in response to affective stimuli reflect concomitant shifts in emotional experience, while other studies have hypothesized that CVC_{PHA} may capture the (more or less successful) exertion of self-regulatory efforts upon exposure to an affective situation.

6.2.2. Phasic CVC regulation as an index of shifts in emotional experience

Based on the polyvagal theory (Beauchaine, 2001; Porges, 1995), CVC_{PHA} is expected to increase at rest or when experiencing relaxation in a safe environment; conversely, in case of stress, CVC_{PHA} is expected to decrease, with potential concomitant increases in sympathetic activation (reflecting the activation of the defensive system). Along with this line of reasoning, it has been predicted that reduced CVC_{PHA} in response to an event or situation should mark negative emotional states or stress more in general, while increased CVC_{PHA} should underlie the experience of positive affective states.

Consistently with this prediction, several studies have found that CVC_{PHA} decreases when performing stressful cognitive tasks (Bosch et al., 2001; Gianaros, van der Veen, & Jennings, 2004; Hamer & Steptoe, 2007; Herbert, Pollatos, Flor, Enck, & Schandry, 2010; Houtveen et al., 2002; Kop et al., 2011; Laborde et al., 2015; Meijman, 1997; Movius & Allen, 2005; Muhtadie et al., 2015; Sloan et al., 2001; Spangler, 1997; Wawrzyniak, Maher, Steptoe, & Endrighi, 2016; Weber, Thayer, Rudat, & Wirtz, 2010; for a review see Overbeek et al., 2014), when anticipating stress and experiencing worry (Hofmann et al., 2005; Gouin et al., 2014; Thayer, 2007, 2010; Thayer, 2007, 2010; Spangler, 1997; Verkuil, Brosschot, Borkovec, & Thayer, 2009a), when experiencing helplessness/hopelessness (Schwarz, Schachinger, Adler, & Goetz, 2003), as well as in response to negative mood induction including public speaking tasks (Codispoti, Mazzetti, Baldaro, Tuozzi, & Trombini, 2001; Pauls & Stemmler, 2003; Spangler & Friedman, 2015; Verkuil, Brosschot, & Thayer, 2014; Zhang, Wang, You, Lü, & Luo, 2015), implicit affective cues (Elliot, Payen, Brisswalter, Cury, & Thayer, 2011), and unpleasant film viewing (Berna et al., 2014; Wang et al., 2013). Conversely, CVC_{PHA} has been shown to increase when experiencing positive emotional states (Gramzow, Willard, & Mendes, 2008; Martens et al., 2010; Matsunaga et al., 2009; Muroni, Crnjar, & Tomassini Barbarossa, 2011; Ritz, Thöns, Fahrenkrug, & Dahme, 2005).

Other lines of research, however, have led to contradictory results. For instance, some studies have found decreased CVC_{PHA} in response to emotional stimuli regardless of hedonic valence, suggesting that CVC_{PHA} may be linked to emotional arousal in general (Codispoti, Surcinelli, & Baldaro, 2008; Frazier et al., 2004; Lane et al., 2009; Marci, Glick, Loh, & Dougherty, 2007; Vaschillo et al., 2008). There has also been evidence for a reverse pattern, with some research detecting reduced CVC_{PHA} in response to pleasant and enhanced CVC_{PHA} in response to aversive stimuli (Herbert et al., 2010; Jönsson & Hansson-Sandsten, 2008; Jönsson & Sonnby-Borgström, 2003; Wittling, Block, Genzel, & Schweiger, 1998). Other studies have revealed inconsistent results when examining different types of emotions: CVC_{PHA} was found to decrease while recalling fear-, happiness-, and sadness- but not anger-related autobiographical events (Rainville, Bechara, Naqvi, & Damasio, 2006), and while viewing a sadness − but not a fear-provoking film (LeBlanc, Unger, & McNally, 2016). Along with this line, Kop et al. (2011) observed changes in CVC_{PHA} in response to a happiness mood induction, while no associations between self-reported emotions and changes in CVC_{PHA} emerged in response to an anger provoking task. Finally, a few studies have shown CVC_{PHA} increases in response to some types of stimuli eliciting disgust including vomiting (Ottaviani, Mancini, Petrocchi, Medea, & Couyoumdjian, 2013), blood, injuries, and surgeries (Baldaro et al., 2001; Bosch et al., 2001; Shenhav & Mendes, 2014; Sokhadze, 2007), but not others (e.g., moral disgust; Ottaviani et al., 2013).

A last group of studies failed to detect significant differences in CVC_{PHA} in response to different types of emotional induction (Etzel, Johnsen, Dickerson, Tranel, & Adolphs, 2006; Herring, Burleson, Roberts, & Devine, 2011; Lackner, Weiss, Hinghofer-Szalkay, & Papousek, 2014; Palomba et al., 2000; Sánchez-Navarro, Martinez-Selva, & Román, 2006). In a recent study employing a wide range of affective videos and pictures, Overbeek, van Boxtel, and Westerink (2012) showed that changes in CVC_{PHA} (as indexed by various RSA metrics) were heterogeneous across types of emotions and frequently nonsignificant. It has thus been argued that methodological factors may exert substantial influence contributing to inconsistent findings: Research has employed different types of emotional induction (e.g., passive viewing of pictures or films vs. active tasks; Bosch et al., 2001), as well as different RSA metrics as an estimate of CVC_{PHA}, with some studies controlling for changes in respiration, and other studies not controlling for this variable. Along with this line, it has been argued that RSA may be no longer a significant discriminator among affective states after accounting for respiratory influences (Kreibig, Wilhelm, Roth, & Gross, 2007; Ritz, Alatupa, Thöns, & Dahme, 2002; Ritz & Thöns, 2002; Shiota, Neufeld, Yeung, Moser, & Perea, 2011).

6.2.3. Phasic CVC regulation as an index of regulatory efforts

Another line of research has proposed CVC_{PHA} to reflect self-regulatory efforts and − consistently with this hypothesis − has observed increased CVC_{PHA} under emotion regulatory tasks. For instance, within-person increases in CVC_{PHA} occurred when participants were instructed to either suppress or reappraise their emotions while discussing an upset topic with another participant (Butler et al., 2006) or while viewing an anger-provoking film (Denson, Grisham, & Moulds, 2011). During an experimental manipulation of self-regulation (i.e., resist eating attractive vs. unattractive food), CVC_{PHA} increased during high self-regulatory effort (eat carrots, resist cookies) compared with low self-regulatory effort (eat cookies, resist carrots; Segerstrom & Solberg Nes, 2007). In another study employing a sample of recovering alcoholics, alcoholics with relatively good self-control over their drinking urge showed increases in CVC_{PHA} in response to an imaginary drinking task, whereas their counterparts with poor self-regulation did not, suggesting that the self-regulated drinkers' successful efforts to restrain themselves led to CVC_{PHA} increases (Ingjaldsson, Laberg, & Thayer, 2003). Finally, during a one-week training focused on the practice of cognitive reappraisal, CVC_{PHA} increased during late training trials (participants were instructed to reappraise while viewing unpleasant images; Christou-Champi, Farrow, & Webb, 2015).

Notably, in a recent study, McGreevy et al. (2015) observed that the efficacy of ER strategies and thus their impact on CVC_{PHA} might be moderated by individuals' personality traits. The authors used distraction (a strategy commonly considered as adaptive) and rumination (a strategy commonly considered as maladaptive) tasks, showing that the two strategies led to different effects on CVC_{PHA} depending on participants' proneness to thought suppression (i.e., a trait tendency to deploy avoidant strategies). Among habitual thought suppressors, the use of distraction led to CVC_{PHA} decreases, while induced rumination led to CVC_{PHA} increases – suggesting that rumination rather than distraction may have had an adaptive function for these individuals. By contrast, among participants who were not prone to thought suppression, the reverse pattern was observed.

6.2.4. Phasic CVC regulation and ER in the context of social interaction

Based on the idea that affect regulation underlies adaptive social behavior, a group of studies has linked CVC_{PHA} and self-regulatory capacity in the context of close relationships (Nealey-Moore, Smith, Uchino, Hawkins, & Olson-Cerny, 2007; Smith et al., 2011). For instance, in one study on married couples (Smith et al., 2011), wives were exposed to either a negative (i.e., describe their husbands' negative personality traits), a positive (i.e., describe their husbands' positive personality traits), or a neutral (i.e., describe their daily schedule) task, followed by a discussion task with their husbands about an ongoing disagreement issue. The authors observed that women's CVC_{PHA} decreased during the negative task and this decrease was larger among the wives whose husbands reported higher negative affect as well higher ratings of their wives as controlling and directive during the task-- consistent with the literature suggesting that CVC_{PHA} decreases reflect negative emotional experience. However, the results also revealed that wives who underwent the negative task showed a significant increase in CVC_{PHA} during the subsequent discussion, while women who were previously engaged in a positive or neutral task showed decreased parasympathetic responding. Overall, the authors concluded that changes in CVC_{PHA} reflected self-regulatory capacity: The negative task made marital quality more salient compared to the positive and neutral task, thus generating greater regulatory efforts (marked by CVC_{PHA} increases) during the disagreement discussion.

A second group of studies has argued that high-quality relationships promote self-regulatory capacity and downregulate physiological stress (indexed by changes in CVC_{PHA}). For instance, in one study using subliminal activation of social ties (Carlisle et al., 2012), the type of relationship was found to influence CVC_{PHA} in response to stressors (a math and a public speaking task): Individuals primed with ambivalent relationship ties displayed larger CVC_{PHA} decreases during stress compared with participants primed with supportive ties. Relatedly, in some studies monitoring HRV throughout a day, individuals showed higher CVC_{PHA} and lower negative affect when engaged in social interactions with a close relevant other (i.e., friends, partner, family members) compared with when they were socializing with a stranger or they were alone (Schwerdtfeger & Friedrich-Mai, 2009; Horsten et al., 1999). Finally, romantic couples were shown to co-regulate CVC_{PHA} levels during an interaction task, with CVC_{PHA} synchrony being stronger for those partners reporting a high-quality relationship (Helm, Sbarra, & Ferrer, 2014).

Finally, a third group of studies has investigated PNS correlates of the social (positive) emotion of compassion, which is defined as a feeling of sorrow evoked by others' suffering together with the desire to sooth that suffering (Goetz, Keltner, & Simon-Thomas, 2010). For instance, Stellar, Cohen, Oveis, and Keltner (2015) found that a compassion-inducing condition (i.e., watching a video of a female student discussing the death of her grandfather) elicited higher CVC_{PHA} levels than a neutral condition (Study 1). In Study 2 and 3, the experience of compassion generated higher levels of CVC_{PHA} when compared to the experience of other positive emotions such as pride and inspiration. In Study 4, CVC_{PHA} increases while viewing a compassion-inducing video were correlated to both subjective experience and outward behavioral expressions of compassion. Similarly, larger CVC_{PHA} increases were observed in extraverted individuals while viewing a sad video clip showing a child crying over his father's death, possibly reflecting an emotion regulation mechanism in front of other people's distress (Park, Van Bavel et al., 2014; Park, Lee et al., 2014).

6.2.5. Correlates of cardiac vagal suppression

Since the polyvagal theory predicts that transient reductions in CVC_{PHA} are an adaptive response to stress promoting active coping with the stressor (Porges, 1995), some research has examined whether decreases in CVC_{PHA} (or cardiac vagal suppression) induced by using stressful tasks are associated with measures of adaptive affective functioning.

Consistent with this prediction, decreased CVC_{PHA} in response to a stressful cognitive task was associated with less perceived loneliness (Muhtadie et al., 2015; Study 2) and better social-emotional accuracy (Study 3). Also, when asking participants to deliver a speech in front of a group of evaluators (Study 4), decreased CVC_{PHA} was related to higher levels of shame, higher blood pressure, and less sociable behavior towards the evaluators among participants who received negative feedbacks, whereas an association with greater sociable behavior emerged among individuals assigned to receive positive feedbacks. The authors thus concluded that vagal suppression was linked to emotional responding that is more flexible and coherent with the context. Likewise, more pronounced decreases in CVC_{PHA} induced by a stressful task were found to exert a protective effect against emotion regulation difficulties among individuals reporting covert narcissism (Zhang et al., 2015), as well as to correlate with self-reports of higher positive affect (Heponiemi, Ravaja, Elovainio, Naatanen, & Jarvinen, 2006), and less social anxiety (Movius & Allen, 2005).

Other studies, however, have suggested that large decreases in CVC_{PHA} may indicate excessive autonomic reactivity to adverse, threat-related stimuli and may be thus associated with maladaptive functioning. For instance, in a prospective study (Gouin et al., 2014), greater vagal suppression during a worry-eliciting task was positively related to trait distress and later predicted larger increases in distress during a stressful period. Another study (Healy, Treadwell, & Reagan, 2011) found that more pronounced decreases in CVC_{PHA} were associated with lower ability to use executive functions as negative affect increased. Along with this line, using a selective attention task, Park, Van Bavel et al. (2014), Park, Lee et al. (2014) found that low but not high CVC_{REST} individuals reacted with reduced CVC_{PHA} to fearful distractors under both low and high cognitive load conditions (suggesting a rigid autonomic stress response to emotionally negative stimuli). Finally, greater vagal suppression has been associated with higher hostility (Sloan et al., 2001), enhanced defensive coping (Pauls & Stemmler, 2003), more implicit anxiety (Verkuil et al., 2009b), higher reactive aggression (i.e., hostile responses to provocation characterized by autonomic hyperarousal; Zhang & Gao, 2015), less self-esteem (O'Donnell, Brydon, Wright, & Steptoe, 2008), higher need for control (Hansen, Godaert, Maas, & Meijman, 2001), and less positive social functioning (Egizio et al., 2008).

Overall, research findings concerning the affective correlates of vagal suppression are controversial. Greater decreases in CVC_{PHA} induced by different types of stressors have been empirically associated with measures of both adaptive and maladaptive affective functioning, while other studies have failed to find any significant association (e.g., Wang et al., 2013).

6.2.6. Phasic CVC regulation when recovering from stress

Although research examining CVC_{PHA} has mainly focused on modulation of CVC_{PHA} under exposure to affective stimuli, some studies have measured phasic changes in CVC during post-stimulation periods, to assess CVC_{PHA} variations when recovering from stressful or adverse events. Adaptive coping with environmental challenges is in fact thought to be marked not only by the capacity to temporally suppress tonic CVC, but also to restore CVC baseline levels after stress (*vagal recovery*).

CVC_{PHA} has been consistently shown to increase during recovery and relaxation after various types of stressful emotional induction (Berna et al., 2014; Bosch et al., 2001; Codispoti et al., 2001; Hamer & Steptoe, 2007; Healy et al., 2011; Houtveen et al., 2002;

Movius & Allen, 2005; Spangler, 1997; Spangler & Friedman, 2015; Verkuil et al., 2014; Wang et al., 2013; Wawrzyniak et al., 2016; Zhang et al., 2015). However, a few studies have found CVC_{PHA} to decrease during recovery from adverse (e.g., disgust-provoking) stimuli which had previously provoked CVC_{PHA} increases (Bosch et al., 2001; Sokhadze, 2007).

Also, empirical evidence has consistently shown that prolonged cardiac vagal reactivity (i.e., inability to quickly return to CVC baseline levels after stress) is linked to maladaptive traits, such as higher emotion regulation difficulties (Berna et al., 2014), higher social anxiety (Movius & Allen, 2005), and lower ego-resiliency (Spangler, 1997). For instance, CVC_{PHA} significantly increased when recovering from an anger-provoking elicitation among individuals reporting low trait difficulties in ER but not in individuals reporting high difficulties (Berna et al., 2014). Likewise, Spangler (1997) found that highly ego-resilient participants showed CVC_{PHA} decreases during challenging situations (i.e., a memory test and an examination) followed by CVC_{PHA} increases during recovery, while low ego-resilient participants were not able to quickly recover and return to CVC baseline levels.

Along with this line, CVC_{PHA} during recovery has been positively associated with CVC_{REST} (Movius & Allen, 2005; Wang et al., 2013; Weber et al., 2010). For instance, Weber et al. (2010) found that low CVC_{REST} individuals maintained reduced levels of phasic CVC throughout the stress and recovery periods, while high CVT_{REST} participants exhibited flexible modulation of CVC (i.e., suppression during stress and increase during recovery).

Notably, it has been shown that emotion regulation may impact phasic CVC regulation while recovering from a stressor. Key et al. (2008) observed that participants who were ruminating after the termination of a stressor had poorer recovery compared to participants who were not ruminating − rumination is commonly considered as a maladaptive ER strategy (see for instance, Nolen-Hoeksema, Wisco, & Lyubomirsky, 2008). Similarly, participants who were asked to a read a news article (i.e., a task to induce distraction) while recovering from an anger-provoking recall task reported less use of rumination and displayed higher CVC_{PHA} than participants receiving no instructions (Neumann, Waldstein, Sellers, Thayer, & Sorkin, 2004). In a recent study (Azam et al., 2015), instructed mindfulness meditation after a cognitive stress induction led to significant CVC_{PHA} increases during meditation compared to a control condition; however, no significant CVC_{PHA} changes during meditation emerged among participants reporting high levels of maladaptive perfectionism (i.e., a stress-related personality trait associated with greater worry and rumination levels). In one study employing verbal harassment prompts delivered while the participants performed a stressful cognitive task, the participants who received an apology (i.e., a strategy to resolve interpersonal conflicts) displayed better recovery from stress (i.e., larger increases in CVC_{PHA}) compared to those receiving no apologies (Whited, Wheat, & Larkin, 2010). Finally, Rottenberg, Wilhelm, Gross, and Gotlib (2003) found that tearful crying after viewing a sad film was associated with significant increases in CVC_{PHA}, under the hypothesis that crying is part of a homeostatic self-regulatory mechanism facilitating recovery from negative affect.

6.2.7. Summary

In a similar way to what we found when examining research on CVC_{REST}, current literature regarding CVC_{PHA} has led to conflicting results. Overall, evidence concerning CVC_{PHA} as a marker of shifts in emotional experience is largely mixed. These studies have consistently found that CVC_{PHA} decreases (vagal suppression) in response to stress (as induced by laboratory tasks) and increases while recovering from stress. Nevertheless, it is unclear whether changes in CVC_{PHA} (increase vs. decrease) in response to affective stimuli are associated with shifts in the experience of (positive vs. negative) emotions.

Research examining the hypothesis that CVC_{PHA} may reflect emotion regulation efforts has returned more consistent results. Several studies have shown that CVC_{PHA} increases when individuals are performing regulatory tasks; also, maladaptive ER strategies as well as trait ER difficulties have been linked to poor CVC recovery after stress.

7. Conclusions and future directions

Starting from the evidence reported in the literature about the relevance of CVC on emotional responding, we have presented a review of the papers published between 1996 and 2016, focusing on the results of 135 papers. A review on this topic appear to be relevant not only because recent reviews on this specific topic are lacking, but also because the high number of studies reported in the literature is matched with a very high rate of conflicting results. This review thus tries to summarize and logically organize the existing data to be used as a guide for future studies.

Drawing on the polyvagal and neurovisceral integration theories, research on CVC_{REST} has been guided by the hypothesis of CVC_{REST} as a physiological marker of individual differences in self-regulation abilities. Studies have thus far tested the relationship of CVC_{REST} with many different facets of ER and related constructs, leading to a growing but fragmented body of research. Also, different research designs have been used to test this relationship. For instance, some studies have employed laboratory paradigms to examine the differences between individuals with high and low CVC_{REST} in their emotional responses to various types of affective stimuli, while other research has privileged an individual-differences approach, examining the associations of CVC_{REST} estimates with a number of self-report measures of ER and coping strategies, as well as of personality traits. Overall, the variety of ER operationalizations, as well as of research methods may have contributed to current mixed evidence.

Future research should attempt to disentangle these conflicting results to gain a clearer picture. Conceptual models of ER may support this attempt guiding the definition of research questions and hypotheses concerning the type of regulatory process involved. For instance, research on ER has distinguished between antecedent- vs. response focused forms of ER (Gross, 2001), showing that regulatory strategies that intervene late in the emotion generation process are cognitively more effortful and less effective at down-regulation negative emotion than strategies that act before emotion response tendencies are fully generated (Gross, 2015). Also, ER strategies may rely on attentional deployment (e.g., shifting attention away from a stressor), cognitive processing (e.g., reinterpreting the meaning of an emotional event), or inhibitory attempts (e.g., refraining from showing outward emotional expression). Notably, regulatory processes may be automatic (also denoted as bottom-up, implicit, or reflexive) or deliberate (also denoted as top-down, explicit, or effortful; Gyurak, Gross, & Etkin, 2011; Todd et al., 2012) and make different cognitive demands (e.g., Gross, 2015; Todd et al., 2012). Future studies could thus further investigate the interplay between CVC_{REST}, emotional, and cognitive regulatory processes. For instance, Spangler, Bell, and Deater-Deckard (2015) have recently shown that habitual suppression, but not reappraisal moderated the relationship between CVC_{REST} and executive function: Although high CVC_{REST} has been associated with better cognitive control (Hansen, Johnsen, & Thayer, 2003), the results showed that at high levels of suppression, high CVC_{REST} corresponded to worse cognitive performance.

Another question concerns the existence of mediation and moderation processes. A few studies have thus far examined (and observed) mediation or moderation paths (e.g., Geisler & Schröder-Abé, 2015; Geisler et al., 2010; Gyurak & Ayduk, 2008; Léon et al., 2009; McGreevy et al., 2015; Ode et al., 2010). Interestingly, these studies have highlighted the potential buffering role of CVC_{REST} against adverse consequences of maladaptive traits (e.g., Geisler & Schröder-Abé, 2015; Gyurak & Ayduk, 2008; Ode et al., 2010).

Third, while most studies have tested the hypothesis of a linear relationship between CVC_{REST} and ER, recent studies have observed significant quadratic associations (Kogan et al., 2013, 2014; Silvia et al., 2014). Thus, a still unanswered question concerns the possibility that extremely high levels of CVC_{REST} become maladaptive and the mechanisms lying behind these negative effects (e.g., Kogan et al., 2013, 2014).

Concerning CVC_{PHA}, there is some consistent evidence that CVC_{PHA} increases when the individual is exerting some ER effort. Future research could further examine this issue, testing whether changes in CVC_{PHA} when attempting to control one's emotions depend on the type of regulatory process involved. For instance, two studies have thus far examined the differential effects of reappraisal and suppression on CVC_{PHA} when down-regulating negative emotions. Butler et al. (2006) found that both participants who were instructed to use suppression and those instructed to use reappraisal showed CVC_{PHA} increases relative to uninstructed controls; however, the largest increase in CVC_{PHA} was seen in the reappraisal condition. Likewise, Denson et al. (2011) observed significant increases in CVC_{PHA} when participants were asked to use reappraisal to regulate their emotions, while CVC_{PHA} increase in the suppression condition fell in between that of the reappraisal and control conditions. These findings seem to suggest that reappraisal (an adaptive ER strategy requiring low levels of cognitive effort) may be linked to larger CVC_{PHA} increases than suppression.

Conversely, the results concerning CVC_{PHA} as a marker of emotional experience appear overall as inconclusive – the most consistent result concerns CVC_{PHA} decreases when faced with a stressor (most commonly, a stressful cognitive task). Although this inconsistency may be partly due to the variety of stimuli and tasks used for emotional induction, these findings seem to suggest that CVC_{PHA} may be not a direct marker of the experience of positive or negative emotions. An open question concerns the role of vagal suppression in ER: Decreases in CVC_{PHA} have been in fact positively associated with both adaptive or maladaptive traits. According to the polyvagal theory, adaptive responses to threat or stressors should be marked by decreased CVC_{PHA} followed by recovery and return to baseline levels; however, most studies have measured CVC_{PHA} during, but not *after* affective stimulation. Future studies assessing CVC_{PHA} could address this gap in the literature by measuring CVC_{PHA} variations during both stimulation and recovery.

Notably, only a few studies have targeted both resting and phasic CVC (e.g., Movius & Allen, 2005; Park, Van Bavel et al., 2014; Park, Lee et al., 2014). It would be important to better understand the association between these two measures, as they are thought to tap distinct aspects of ER (i.e., individual differences in regulatory abilities vs. the exertion of regulatory efforts).

Finally, methodological recommendations concerning the measurement of respiration-linked HRV and its interpretation as an index of CVC have been recently suggested for future research to obtain results that are comparable across studies and that may contribute to knowledge advancement in this field (see for instance, Laborde et al., 2017). Among these methodological issues, we mention the selection of the type of RSA metric (which has been highly variable across studies; Allen et al., 2007) and the control of respiration when using RSA as an index of CVC (which has been a topic of a large debate; Grossman & Taylor, 2007; Grossman, Karemaker, & Wieling, 1991; Kreibig et al., 2007).

Despite the conflicting results and the above reported methodological issues, we have shown that there is some convergence of results supporting the use of CVC as a noninvasive, objective marker of emotional responding and emotion regulation. Resting CVC has been associated with down-regulation of negative affect, use of regulatory strategies, and flexible emotional responding. Concerning phasic changes, research has consistently found decreased RSA in response to laboratory stressful tasks, while RSA increases have been shown to reflect either regulatory efforts or recovery from stress. Future meta-analyses may further test these relationships.

Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.biopsycho.2017.10.008.

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