2017

Synchrony and concordance: A multilevel analysis of the effects of individual differences during a CO2 challenge

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Synchrony and concordance: A multilevel analysis of the effects of individual differences during a CO_2 challenge

A thesis submitted in fulfillment of the requirements for the degree of Master of Science at Virginia Commonwealth University

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May 9th, 2017

Acknowledgements

With the completion of this thesis, I would like to thank several people. First, Dr. Scott Vrana has been a patient, supportive mentor throughout this project, and this process has helped me grow as a professional and researcher. I would also like to thank my committee members, Dr. Roxann Roberson-Nay and Dr. Charles Calderwood for their time and commitment to this project. I thoroughly enjoyed hearing their ideas and look forward to future research. Finally, I would like to thank my family and friends for their continued support and encouragement.

This study was funded by a National Institute of Mental Health grant to Dr. Roxann Roberson-Nay (K01MH080953) and a National Institute on Aging grant to Dr. Bethany Teachman (R01AG033033). Preliminary

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Abstract

SYNCHRONY AND CONCORDANCE: A MULTILEVEL ANALYSIS OF THE EFFECTS OF INDIVIDUAL DIFFERENCES DURING A CO2 CHALLENGE

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A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science at Virginia Commonwealth University

Virginia Commonwealth University, 2017

Major Director: Scott R. Vrana, Ph.D., Professor, Department of Psychology

Keywords: emotion, synchrony, concordance, individual differences, anxiety

Emotion theories posit that emotion systems (e.g., behavior, self-report, physiology) should be related when an emotion is being elicited because this serves an adaptive purpose and allows the individual to respond appropriately to the present situation. Oftentimes, this coherent relationship is not found, and research has hypothesized that the type of analyses used and lack of examination of individual differences could be affecting this relationship. Most studies examine the relationship between emotion systems between-subjects when within-subjects analyses may be more appropriate. The present study examined the relationship between self-reported distress (SUDS) and heart rate, and whether trait differences of anxiety sensitivity and heart rate variability affect that relationship. Undergraduate students (N = 294) completed an anxiety sensitivity measure and their heart rate variability was calculated prior to undergoing a 7.5% CO2 challenge. SUDS was collected 11 times throughout the challenge and heart rate was collected continuously. Consistent with studies examining both concordance (between-subjects correlation between systems) and synchrony (within-subjects correlation between systems), synchrony was found between heart rate and SUDS, but concordance was not found between the two variables. Contrary to our hypotheses, neither anxiety sensitivity nor heart rate variability predicted synchrony between heart rate and SUDS. Our results suggest that synchrony is a more appropriate measure of adaptive emotional response than concordance because synchrony allows for examination of coordination of emotion systems over time.

Introduction

Hodges (1968) stated that one of the most interesting phenomena in psychological research is the discordance between a person's physiology and their self-report during a stressor. Though there is a widely-held belief that when a specific emotion is being elicited an individuals' self-report and physiology should be synced together, studies generally show that there is not a concordant relationship between the two. Hodges cites Schachter's (1962) theory in which he proposes that "the identification of a specific emotion is the result of a reaction to a particular situation that leads one to label physiological arousal as having meanings of a particular emotional state". Hollenstein and Lanteigne (2014) cite the canonical fear response, which presumably involves a concordant combination of a threat appraisal, a fearful outward appearance, increased sympathetic arousal, and a desire to escape the situation. These conceptualizations assume that when one experiences an emotion, one also experiences a change in both behavior and physiology. However, research generally does not support this assumption.

Numerous terms have been used to describe the relationship between physiology and self-report. Rachman and Hodgson (1974) describe synchrony and desynchrony and concordance and discordance in the context of fear and avoidance. They state that

> ...when fear and avoidance are not co-varying, one can speak of a discordance between the two at any particular point: when there is a high correlation between the two then one has concordance. The terms synchrony and desynchrony have a similar but not identical meaning to that of concordance and discordance. It is suggested that synchrony and desynchrony should be restricted to *changes* in fear and avoidance which either vary together (synchrony) or vary independently or inversely (in both of these cases, one has desynchrony).

Discordance occurs when correlations between measures at a specific time are low, and desynchrony describes the occurrence of low or no correlations between change scores from different timepoints (Hodgson & Rachman, 1974). Although both concordance/discordance and synchrony/desynchrony have been used in the literature to describe the relationship of measures between-subjects, only synchrony/desynchrony has the ability to accurately capture the relationship between changes within-subjects over time. Based on the definitions proposed by Rachman and Hodgson (1974) and the analyses that will be used in this paper, the terms synchrony and desynchrony will be used to describe within-subjects changes over time, and concordance and discordance will be used to describe the between-subjects relationship between measures. Although many studies have used a number of terms (e.g., response coherence, response components, synchronization; see Hollenstein & Lanteigne, 2014) to describe the relationship between emotion systems, we used synchrony/desynchrony when these studies examined within-subjects and concordance/discordance for between-subjects in order to facilitate comprehension.

Many approaches have been taken to examine synchrony and concordance. Studies of the relationship between psychophysiological and self-report measures have been conducted in clinical and non-clinical samples (Eifert, Zvolensky, Sorrell, Hopko, and Lejuez, 1999; McTeague and Lang, 2012), have used paradigms to elicit different emotions (Campbell and Ehlert, 2011; Grossberg and Wilson, 1968; Mauss, et al., 2011), have examined individual differences (Dan-Glauser and Gross, 2013; Ruggiero, Black, Larkin, and Taylor, 2002; Salmon, 2001), have used different physiological and behavioral measures (Lang, Melamed, and Hart, 1970), and have induced different levels of arousal and demand (Watson, Gaind, and Marks, 1972). Results have been mixed regardless of these factors (Alpers & Sell, 2008), with results showing that there is concordance and discordance between variables measuring physiological output, self-report, and/or behavior.

Hollenstein and Lanteigne (2014) propose three explanations for the mixed findings of concordance between individuals' self-report, psychophysiological output, and behavior. The first explanation is that the theories used to explain the relationship between these variables are "wrong". These authors state that instead of analyzing emotion as "an abstract, theoretical construct", it should be defined by more objective, observable definitions. The lack of moderators and individual differences included in this research is the second explanation proposed by Hollenstein and Lanteigne (2014). Third, these authors explain that the methodology commonly used is poor and does not accurately account for the phenomena occurring. These concerns will be addressed in the literature review.

The primary goal of this project is to examine heart rate variability (HRV) and anxiety sensitivity (AS) as individual difference variables affecting the relationship between physiological and self-report measures. HRV is a measure of self-regulation and can be used to determine how an individual will respond to a stress-inducing situation (Miu, Heilman, & Miclea, 2008). The neurovisceral integration model is a framework which integrates affective regulation, attentional regulation, and heart rate variability, and describes how adaptively an individual will respond to one's environment (Thayer & Lane, 2000). Because people with greater baseline HRV exhibit greater emotion regulation (Porges, 1991) and respond more adaptively to their environment, it is hypothesized that individuals with greater HRV will show a more adaptive and integrated response to the CO2 challenge and therefore exhibit a more synchronous relationship between HR and SUDS during the challenge.

Another individual difference that may influence the relationship between physiology and self-report is one's level of anxiety sensitivity, which is one's fear of anxiety-related symptoms (Reiss and McNally, 1985). Increased anxiety sensitivity levels predict anxious responding in the laboratory (McNally & Eke, 1996; Zvolensky, et al., 2002). The interoceptive sensitivity hypothesis states that individuals with high AS are "…characterized by an enhanced ability to accurately detect arousal-related bodily sensations" (Stewart, Buffett-Jerrott, & Kokaram, 2001). Based on this hypothesis, we propose that individuals with higher AS will exhibit a more synchronous relationship between HR and self-reported distress because these individuals will be more aware of their physiological symptoms and will respond synchronously with their self-report.

An additional goal of this project is to use a within-subjects approach in order to examine synchrony. Reisenzein (2000) states that using a between-subjects data analysis method to study the relationship between physiological and self-report measures of emotion is "suboptimal" compared to using a within-subjects approach, because there are a number of inter-individual differences that exist between-subjects, and using a between-subjects analysis does not account for those differences. The Reisenzein (2000) study, which will be elaborated on further, supports the notion that methodology can affect the degree of synchrony found between measures. Further, Sze, Gyurak, Yuan, and Levenson (2010) posit that within-subjects analyses may represent the construct of emotion better than between-subjects analyses because within-subjects analyses account for the relationship between emotion systems over time.

In the present study, we used the carbon dioxide (CO2) challenge in order to induce panic and anxiety symptoms in participants. This study involves participants breathing in 7.5% CO2 air for eight minutes, introduced without the participants' awareness after five minutes of breathing room air. This method has proven to reliably produce panic-like symptoms (e.g., sweating, shortness of breath) in the laboratory among both clinical (Seddon et al., 2011) and non-clinical samples (Bailey, Argyropoulos, Kendrick, & Nutt, 2005). A number of stress-inducing tasks have been used in the literature; however, the CO2 challenge has not been used in the concordance/synchrony literature. We used this paradigm as a means to induce anxiety in a non-clinical sample. Anxiety sensitivity (AS) and heart rate variability (HRV) were measured prior to the experimental manipulation as individual differences in order to examine whether they moderated the synchrony between an individuals' heart rate (HR) and Subjective Units of Distress (SUDS) ratings during the CO2 challenge task.

Review of the Literature

In the following review, the literature on the relationship between different behavioral, autonomic, and self-report responding in emotional or stressful situations will be critically examined. Next, an examination of the Hollenstein and Lanteigne (2014) article will be done in order to identify different factors that may be contributing to the discrepant findings in the concordance and synchrony literature. These will include individual differences, methodological concerns, and theoretical considerations. Then, the inclusion of Lang's (1979) bio-informational theory will be explored as a potential assumption to describe the findings in the literature and as a theory to adopt and use when examining these relationships. Anxiety sensitivity and heart rate variability will be examined as potential individual differences that might affect synchrony between self-report and heart rate response to the CO2 challenge. Specifically, the interoceptive sensitivity hypothesis and the neurovisceral integration model will be described in relation to AS and HRV respectively. Lastly, a review of the carbon dioxide challenge will be done in order to justify its use in the present study as a paradigm that can reliably induce panic-like symptoms.

Synchrony/Desynchrony and Concordance/Discordance

The earliest literature examining concordance and synchrony between the “loosely coupled” measures of emotion was done in the 1970s, in treatment outcome research. Grossberg and Wilson (1968) instructed participants with phobias to visualize a personally frightening and neutral scene. Only during the fear-provoking visualization was there concordance (r=.60) between the group’s reported vividness of the imagined scenario and heart rate. Lang and colleagues (1970) conducted a study examining concordance of physiological symptoms and self-report of imagined fearful scenarios in a sample of individuals with social anxiety or spider phobia. Results showed that heart rate and self-reported fear were related during imagined scenarios of individuals’ own fear hierarchies, such that increases in heart rate were associated with self-reported anxiety level (r=.52). Watson and colleagues (1972) examined heart rate and self-reported fear in subjects with varying phobias, and participants were read fearful scripts pertaining to their specific phobia. In subsequent trials, the individuals were exposed in-vivo to their fear. There was discordance between heart rate, which decreased over sessions, and self-reported fear, which remained the same over sessions. Thus, a few of the early studies did find concordance in samples of fairly anxious individuals. However, the subsequent literature has been much more mixed.

For example, in a review of 49 studies that used the Trier Social Stress Test (TSST), which involves subjects delivering a speech for a job interview and then completing an oral serial subtraction in front of a group of “experts”, to examine concordance in individuals in a laboratory setting, Campbell and Ehlert (2012) found generally weak concordance. Participants are told that they will be videotaped and their performances will be evaluated by professionals for presentation style and nonverbal behavior. Inclusion criteria for this review included use of the TSST or the TSST with slight variations, at least one measure of subjective experience, and associations of physiological and subjective measures based on correlation or regression. Indices of psychophysiology were salivary cortisol (61% of the studies); heart rate, systolic and diastolic blood pressure (24% of the studies); plasma cortisol (18% of the studies); and plasma adrenocorticotropic hormone (12% of the studies). Individuals' subjective reports of emotion were taken prior to the stress task as well as after its completion in 29% of the studies, after the stress exposure in 29% of the studies, repeatedly during the course of the experimental procedure in 24% of the studies, and in 20% of the studies a post and a pre-post assessment were combined. There were overall weak associations between physiological measures and self-report, such that, of the 30 studies using salivary cortisol in their study, only eight found significant correlations between that measure and subjective emotion experience. Additionally, of the 12 studies that assessed for heart rate and/or systolic and diastolic blood pressure, only three studies showed a significant association between subjective stress and these cardiovascular measures, and correlation coefficients showed a range between 0.3 and 0.5, which the authors describe as "weak" associations. Campbell and Ehlert (2012) conclude that the response systems involved with stress reactivity represent "multiple independently varying components", and they cannot be studied without taking moderating factors (e.g., emotion regulation, appraisal processes, social desirability, and motivation) into account. Further, they posit that discordance may "…reflect a normal reactivity pattern and/or results from various methodological issues". They state that certain factors that influence concordance include underlying psychological traits and states (e.g., emotion regulation, appraisal processes, social desirability, and motivational engagement). Campbell and Ehlert (2012) state that consideration of these factors can help explain the different patterns of responses and desynchrony within individuals.

An important distinction in the concordance/synchrony literature is whether studies examine both within-subjects and between-subjects or solely between-subjects relationships between emotion systems. Alpers and Sell (2008) examined the relationship between heart rate and self-reported fear both within- and between-subjects and evaluated whether psychophysiological activation pre-treatment predicted treatment outcome in a group 10 claustrophobic patients by exposing them to small spaces. In order to calculate the inter-individual correlations, the raw values of HR and self-reported fear during each session were calculated. The results revealed that there was little concordance between individuals during six sessions of exposure, and the correlations for the six sessions were rs = .27, .51, .53, .35, .33, and .19 (interpreted as low concordance). The researchers also conducted intra-individual Pearson correlations between the raw values of both heart rate and SUDS ratings across the six sessions, and found a synchronous decrease in both heart rate and self-reported fear for six of the ten participants across the six sessions. The mean z-score for the within-subjects correlation was .49 for these six participants, which the authors interpreted as a synchronous change. This is important because it shows that only examining the between-subjects relationship between variables ignores any within-subject variation that is present.

As noted previously, numerous studies have described the concordance/discordance and synchrony/desynchrony that exists between emotional subsystems. Researchers believe that an individuals' self-report, physiological response, and behavior will be related based on the canonical fear response. The varied results of the studies described do not completely support this belief. The lack of consistent results in the literature have led some to suggest that one or more factors are affecting the expected concordance and synchrony between emotional subsystems. The next section will review different factors that affect concordance and synchrony and the implications these will have on this study.

Factors that Affect Concordance and Synchrony

Individual Differences. Hollenstein and Lanteigne (2014) offer three explanations for the limited support for concordance that exists between emotional subsystems in research studies. The first reason that Hollenstein and Lanteigne (2014) provide is the relative neglect of including moderators in the research. They propose that inclusion of individual differences could show different patterns of response systems within-subjects. Numerous studies that do not assess for individuals' regulatory processes and other individual differences may be ignoring important information regarding how these factors affect the relationship between individuals' physiology and self-report. It is important to account for these differences because individuals who are better at relaxing and modulating their heart rate may show a more desynchronous relationship between heart rate and self-report. A number of studies have examined the role of emotion regulatory processes on emotion systems, and found that emotion regulation affects the relationship between individuals' physiological and self-reported measures of emotion.

Previous research has shown that individuals who are instructed to regulate their emotions are able to do so, with effects including decreasing their heart rate, increasing sympathetic activation, and increasing blood pressure (Gross, 1998). These results suggest that individuals can effectively use regulatory strategies to modulate their physiological response, which can affect the synchrony between emotional subsystems. Dan-Glauser and Gross (2013) studied an undergraduate sample to see the effects of how two types of suppression (expressive and physiological) influence the relationship between emotion experience (participants used a dial to self-report their degree of negative or positive feelings), emotion-expressive behavior (facial behavior), and autonomic responses (electrocardiography, blood pressure, finger pulse, skin temperature, and respiration). Participants were randomized to three conditions and were then instructed to observe positive and negative pictures. The conditions included: unregulated, expressive suppression ("don't show emotions"), or physiological suppression groups ("don't react"). Results showed that participants in both the expressive and physiological suppression groups had significantly lower concordance between all three measures than the unregulated condition.

Butler, Gross, and Barnard (2014) tested the effects of two different forms of emotion regulation on participants' subjective experience, expressive behavior, and physiology after watching an emotionally arousing film and discussing the film with other participants assigned to different emotion regulation conditions. Participants were either assigned to an uninstructed control group, a suppression group, or a reappraisal group, and partners were randomly assigned after watching the film clip. After the conversations, participants watched the recorded video of themselves and used a dial ranging from "positive", "neutral", and "negative" to continuously rate how they remembered feeling during the conversation (emotion experience). A blind coder was used to code each of the participants' videos for positive and negative emotion expressions (emotion expression). Results showed that, compared with the uninstructed condition, participants in the suppression condition (e.g., those instructed to behaviorally not show any emotion) showed lower concordance for emotion experience and inter-beat interval, emotion experience and both negative and positive expression, and inter-beat interval and both negative and positive emotion expression. Compared with the uninstructed group, the reappraisal condition (e.g., those instructed to reevaluate the situation more positively) showed lower concordance for experience and negative expression and inter-beat interval and negative expression.

Regulatory processes are not the only moderators that have been shown to affect and potentially "disrupt" synchrony. Peasley-Miklus, Panayiotou, and Vrana (2016) conducted a study to assess processing of imagined emotional stimuli in students who endorsed a range of alexithymia traits. Alexithymia is characterized by difficulties with identification and communication of emotions and an external thinking style, and it is believed to exist on a continuum in the general population (Parker, Keefer, Taylor, & Bagby, 2008). Participants in the study were read a script that pertained to a specific emotion (anger, fear, joy, neutral, action) and were asked to continue to imagine the scene after the script was read. Participants went through two trials for each emotion, for a total of 10 trials. Results supported the authors' hypotheses that those who endorsed more alexithymic traits would show desynchrony between their physiological and self-report experience of the emotional scenarios, such that the strength of the relationship between arousal and heart rate was weaker as alexithymia increased. These results provide evidence of the role individual differences in emotion regulation play in synchrony.

Another individual difference that may affect synchrony between emotion subsystems is physical fitness and respiratory health. Salmon (2001) and Schlicht (1994) state that physical fitness could have differential effects on individuals' physiological reactivity, resulting in desynchrony between expressed emotion and physiology. For example, individuals who exercise regularly may have a lower resting heart rate than individuals who lead a more sedentary lifestyle, and these physically active individuals may be more likely to exhibit a consistent heart rate over time, even during distressing scenarios. Further, Sze and colleagues (2010) posit that individuals who are trained in different levels of body awareness (Vipassana meditators, modern and ballet dancers, and controls) may exhibit different levels of awareness towards their bodies and show greater synchrony if they have more training in body awareness. It was hypothesized that there would be greater synchrony between subjective experience and heart period in the meditators, followed by the dancers, and then the control group. Emotional states were induced by having participants watch intensely negative, intensely positive, and neutral film clips. Results supported the researchers' hypotheses, and the individuals who exhibited greater body awareness showed greater synchrony between their heart period and self-reported experience of emotion within-subjects.

Based on these results, it is clear that emotion regulatory strategies and other individual differences affect the degree of synchrony between psychophysiological and self-report measures. For the purpose of this study, AS and HRV will be examined as individual differences. Based on the literature for these two individual differences summarized later in this literature review, it is hypothesized that higher AS and higher HRV will each be associated with greater synchrony between HR and SUDS.

Methodological Concerns. The second explanation that Hollenstein and Lanteigne (2014) offer are specific methodological concerns that may be negatively affecting the examination of synchrony and concordance. The authors state that studies examining synchrony or concordance may not be using paradigms that are adequately eliciting emotions. It has been suggested that high intensity, basic emotions such as fear may elicit more concordant responses than general emotional states (Friedman, Stephens, & Thayer, 2014). Levenson (1994) bases this on the assumption of the discrete emotions theory and the idea that there is a set of basic emotions that evolved and served the adaptive function of survival in fight or flight scenarios. Because these emotions are thought to serve an adaptive function, it is believed that the emotion systems must be concordant in order for individuals to survive. Reisenzein (2000) adds that an additional reason for low correlation among emotion responses may be measurement method factors. For example, in their review of 49 studies examining the relationship between psychophysiology and subjective experience of emotion, Campbell and Ehlert (2012) report that in 58% of these studies self-report of emotional state were either collected both pre- and post-stressor or only a single assessment post-stressor. Because emotional state can change so rapidly and retrospective bias could cloud individuals' reports, measurements of subjective emotion only before or afterwards reduce the amount of concordance found.

An additional methodological consideration that is offered is the method with which the data are analyzed. Most studies use a between-subjects approach in order to analyze concordance of emotional response. Reisenzein (2000) contends that a within-subjects approach is more appropriate because this method of analysis controls for "…factors that could in previous studies have lowered the correlations among the components…". Highlighted previously, Alpers and Sell (2008) examined both the between- and within-subjects relationships. The between-subjects analysis of heart rate and self-reported fear yielded non-significant small to medium size correlations, but the within-subject correlations were significant within and across sessions, indicating a synchronous change.

Bellemare, Bissonnette, and Kröger (2014) state that within-subjects designs allow researchers to test theories at the individual level. The data analysis methods used are important because of the effects that individual differences have on the relationship between physiology and self-report. A between-subjects design poses issues for detecting these individual differences because it does not parse out individual variability, which has been shown to affect the relationship between self-report and physiology when within-subjects analyses are used

(Hollenstein and Lanteigne, 2014). A within-subjects analysis of the data would take into account individual differences that exist between-subjects. For example, an individual with higher AS may be more likely to react with distress to a CO2 challenge than someone with lower AS. This may skew the results because a between-subjects approach does not accommodate for the individual differences that may influence how synchronous an individual's emotional systems may be. Using a within-subjects analysis allows researchers to account for differences that may have an effect on the synchrony of a relationship between emotion systems. A goal of this study is to use a within-subjects approach in order to examine the effects that AS and HRV have on each individuals' relationship between HR and SUDS. A multi-level modeling (MLM) approach will be used in order to examine these relationships.

Theoretical Considerations. A third concern is that the theoretical assumptions behind the concordance literature may not be consistent with current theoretical views of emotion. Hollenstein and Lanteigne (2014) propose that based on widely-accepted theories of emotion, it can be assumed that an emotion is experienced and an individual responds coherently to said emotion. Based on this model, different measures of emotion should be concordant with the unobservable experience of emotion, and therefore the different measures of emotion should be concordant with each other. However, there is no way to know if an individual is experiencing an emotion. Hollenstein and Lanteigne (2014) state that, "…concordance is still seen as important, yet only as a bottom-up process through which we can discover functional combinations via inductive rather than deductive inquiry". The authors believe that a more advisable way to examine concordance would be to use "inductive inquiry" and observe relationships between different "observables" rather than assume that because a specific emotion is being elicited that these observables should have a relationship.

Taking Hollenstein and Lanteigne's (2014) argument into account, the bio-informational theory proposed by Lang (1979) provides an explanation for the discordant results of emotion systems. Lang (1979) proposes that concordance is not guaranteed because measures of self-report, physiology, and behavior are relatively independent. Lang draws upon the perceptual and emotional imagery literature and describes the process by which individuals experience and interpret an emotional event. Lang (1979) describes three types of propositions, defined as "a general abstract form of representation [that is] not limited to semantic knowledge", that play a role in one's emotion memory network. The first type is a stimulus proposition, which involves the stimulus characteristics of the memory. This could include information about the event, the context, and the situation. The second type is the response proposition, and this includes any behavioral or physiological response that is evoked by the stimulus. The last proposition is the meaning proposition. This involves attributing meaning to the emotional mental representation for the individual. When an emotional memory is processed, all three types of propositions are accessed through spreading activation. Response propositions are particularly important because they are direct efferent activity. For example, if one is in a dark alley and hears menacing noises, the response proposition may involve running, and heart rate and muscle tension in the legs will automatically increase to support the behavioral activity. In a research study that involves imagining this situation, these response propositions would automatically be activated, increasing heart rate and muscle tension even though the final behavioral output (running) does not occur. If an individual experiences a fear-eliciting situation, the mental image created by that event will generate a different reaction depending upon the varied propositions that are involved in the network

Friedman and colleagues (2014) state that the propositions for a response for each subsystem (e.g., physiological, self-report, and behavioral) may not be activated simultaneously when accessing an emotional image; thus concordance should not be expected. Lang (1979) stated that how much of the network is activated depends on the stimulus that is activating the network and on the strength of association between the propositions. There are individual differences that affect the efferent output of each individual, such that some individuals may have high coherence between response propositions and others may have low coherence resulting in discordance between measures.

The findings from the synchrony and concordance literature described above show that finding a synchronous or concordant relationship between a physiological and self-report measure is difficult, and Hollenstein and Lanteigne (2014) suggest three different explanations about why this is so. One of the most important explanations is that individual differences may obscure relationships between physiological and self-reported response to emotion. The primary goal of this study is to examine individual differences that may be affecting the relationship between physiology and self-report. This study examined whether anxiety sensitivity and heart rate variability affect the degree of synchrony within-subjects. The next sections of this paper review these two variables and the role they may have in affecting the synchrony of HR and SUDS during a carbon dioxide challenge.

Anxiety Sensitivity

Anxiety sensitivity is defined as the fear of anxiety and other anxiety-related sensations and the effects that these symptoms may have on an individual (Reiss and McNally, 1985). Anxiety pathology is often characterized by a psychological vulnerability-stress model (Alloy, Kelly, Mineka, & Clements, 1990). This model theorizes that certain psychological vulnerabilities heighten the risk for maladaptive anxious and fearful responding. Anxiety sensitivity is a well-documented risk factor for fearful responding. The Anxiety Sensitivity Index is meant to assess individuals' concern over their physiological symptoms by asking questions such as, "It scares me when I feel shaky" and "It scares me when I become short of breath". Thus, the Anxiety Sensitivity Index is an appropriate tool to use in challenges that induce hyperventilation and related symptoms because "…the physiological challenge may be more related to primary appraisals related to evaluating bodily sensations…" (Zvolensky et al., 2002).

Anxiety sensitivity is related to synchrony between self-report and heart rate because AS "[amplifies] anxious and fearful responding to potentially anxiety-evoking stimuli" (Taylor and Cox, 1998), and it has been shown to affect the relationship between psychophysiological response and self-reported distress (Zvolensky et al., 2002). In their study, Zvolensky and colleagues (2002) hypothesized that AS would be a better predictor of emotional response to the hyperventilation challenge than perceived stress. Results supported this hypothesis. Scores on the ASI accounted for 12% of the variance predicting post-challenge SUDS ratings. Additionally, higher scores on the ASI were associated with higher SUDS ratings, and a *t*-test revealed that there was a statistically significant change in HR and SUDS ratings from baseline to post-challenge in the hyperventilation task. Thus, it would be expected that individuals who are at a heightened risk to respond anxiously to a stimulus are likely to respond synchronously because this amplification of fearful responding would occur in both physiology and self-report. In our study we expect that individuals with higher anxiety sensitivity will exhibit a synchronous relationship between HR and SUDS within-subjects.

Stewart and colleagues (2001) describe the interoceptive sensitivity hypothesis, which states that "…nonclinical high AS individuals are characterized by an enhanced ability to accurately detect arousal-related bodily sensations”, and that individuals with increased anxiety sensitivity will experience arousal-related somatic sensations and respond with anxiety (Ehlers, 1993). The study conducted by Stewart and colleagues (2001) examined the effects of anxiety sensitivity on heartbeat awareness and heart rate reactivity in a nonclinical sample. It was hypothesized that individuals with high AS would show greater increases in stress-induced heart rate and would be more aware of their heartbeat compared with the low AS group. Results showed that there were no differences in heart rate reactivity between the two groups, but the high AS group was significantly more accurate in predicting their actual heart rates.

These results suggest that individuals with high AS are better able to estimate their heart rate than individuals with low AS, and this supports the interoceptive sensitivity hypothesis. Sturges and Goetsch (1996) report that individuals who are more fearful of interoceptive symptoms are likely to be more motivated to monitor these symptoms. Based on these results, it is hypothesized that individuals with high AS will be more likely to self-report higher distress when their heart rate is higher, because they will be more attuned to their heart rate. Thus, individuals with higher AS will exhibit a more synchronous relationship between HR and SUDS because they will be paying more attention to their symptoms.

Heart Rate Variability

Chalmers, Quintana, Abbott, and Kemp (2014) state that heart rate variability (HRV) is “the fluctuation of heart period over time…and is an important marker of psychological well-being”. It is argued that “HRV reflects the degree to which cardiac activity can be modulated to meet changing situational demands” and is influenced by both the autonomic nervous system and the central autonomic network (Appelhans & Luecken, 2006). Porges (2007) describes the relationship between emotion regulation and HRV and states that “individuals with low HRV have increased difficulties in emotion regulation in contexts requiring it". Based on the role that emotion regulation plays in adapting to different situations, it is hypothesized that individuals with higher HRV will show a more synchronous relationship between HR and self-reported distress because those with higher HRV may have better emotion regulation and will respond more adaptively than an individual with lower HRV.

Laborde, Lautenbach, and Allen (2015) state that "effective emotional functioning reflects an effective way of coping with stressful situations". They cite the neurovisceral integration model (Thayer & Lane, 2000), which postulates that the self-regulatory responses of emotions allow for "an optimal functioning of a broad range of regulatory functions serving goal-directed behaviors". This model is similar to the canonical fear response because all three systems of emotion ideally work together to respond adaptively. Thayer and Lane (2000) assert that disorders of affect "…may be viewed as a kind of distorted emotional state space in which an individual is unable to shift into an emotion that is appropriate for a given set of environmental demands". HRV is a measure of self-regulation that provides information regarding how adaptively one responds to one's environment (Porges, 1991). Thayer and Lane (2000) propose that "measures of cardiac vagal tone (e.g., HRV) index the efficiency of central-peripheral neural feedback mechanisms". Based on this model, an individual with higher HRV, which is associated with the ability to self-regulate, will more adaptively respond in a distressing situation that requires response, so their heart rate will tend to go up. Conversely, individuals with lower HRV will show poor self-regulation and decreased behavioral flexibility when faced with a stress-provoking situation. This may result in no heart rate change or decreased heart rate even in distressing situations requiring an adaptive response. Thus, it is hypothesized that individuals with higher HRV will show a more synchronous relationship between HR and SUDS during the CO_2 challenge.

Carbon Dioxide Challenge

Carbon dioxide (CO_2) challenge tasks have historically been employed as a means to induce panic symptoms (Rassovsky & Kushner, 2003). Although this paradigm is generally used to understand panic symptomatology in panic disorder (Rassovsky & Kushner, 2003), it has been used as an experimental tool to examine other anxiety disorders (Seddon et al., 2011) and non-clinical samples due to its ability to induce physiological reactivity. For example, Forsyth, Eifert, and Canna (2000) showed that by using a repeated 20% CO_2 inhalation procedure, 55.2% of the healthy volunteers responded with symptoms similar to a panic attack. Further, among 20 non-clinical participants who inhaled 7.5% CO_2 for a duration of 20 minutes (Bailey et al., 2005), systolic blood pressure and heart rate were significantly increased. These results suggest that the CO_2 challenge is an appropriate paradigm to use in order to increase physiological arousal and distress in non-clinical samples.

Studies employing the CO_2 challenge have used a range of gas concentrations from 7% CO_2 to 35%. Rassovsky and Kushner (2003) state that the 35% concentration is likely to evoke more immediate panic symptoms that are short-lasting because the dose is higher. Because this study is interested in lower level of anxiety symptoms that increases over time in order to examine individual differences in response to these symptoms, a 7.5% CO_2 concentration will be used to induce anxiety symptoms for this study.

Statement of Problem

Studies examining the relationship between self-reported emotion and physiology have not consistently found concordance between these variables. Researchers have sought explanations for why concordance is not found consistently, and Hollenstein and Lanteigne (2014) consider the methodology, theory, and the disregard of examination of individual differences to be major factors affecting the results, and they reason that addressing these concerns would yield more concordant relationships between variables. Most researchers have examined concordance using between-subjects data analyses, but there seems to be more evidence that supports examining synchrony, a within-subjects effect.

This study examines individual differences in synchrony by analyzing the effects that AS and HRV have on the relationship between HR and SUDS. Lanteigne, Flynn, Eastabrook, and Hollenstein (2014) state that "the within-subjects approach allows for better understanding of how an individual's concordance or discordance relates to individual difference factors". It is predicted that individuals with higher AS will be more likely to self-report higher distress when their heart rate is higher, because they will be more attuned to their heart rate. Additionally, it is hypothesized that individuals with higher HRV, which is associated with the ability to self-regulate, will more adaptively respond in a distressing situation that requires response, so their heart rate and self-reported distress will increase. Thus, both higher AS and higher baseline HRV will be related to both greater synchrony between heart rate and self-reported distress during a CO2 challenge.

Research Hypotheses

(1) Higher SUDS will predict higher heart rate between-subjects

(2) Higher SUDS will predict higher heart rate within-subjects.

(3) There will be greater synchrony within-subjects between HR and SUDS for those who are higher on anxiety sensitivity.

(4) There will be greater synchrony within-subjects between HR and SUDS for participants with higher baseline HRV.

Method

Participants

Data were analyzed using participants from a larger study that was designed to examine how anxiety-related control attributions predicts anxious responses during multiple sessions of a biological stressor (Gorlin, Beadel, Roberson-Nay, & Teachman, 2014). This study examined the effect that HRV and ASI have on the relationship between HR and SUDS during Session 1 of the biological stressor from the larger study. Participants (*N* = 294, 58.6% female, 54.8% Caucasian) were recruited from undergraduate samples at two large universities in the American Southeast who participated in exchange for course credit or financial compensation. The average age of participants was 19.8 years (range = 18-49 years). Participants were recruited based on completion of a department-wide preselection survey (e.g., SONA), or via recruitment flyers posted on each university's campus. Following previously used standard health-based exclusions for employing the maintained CO2 inhalation procedure (Garner, Attwood, Baldwin, James, & Munafo, 2011), participants were excluded from the study if they reported any of the following: asthma or a serious, unstable medical condition, past or current episodes of psychosis, or having taken an antidepressant or other psychotropic medication within the past 4 weeks.

Procedure

Informed consent was obtained from all participants included in the study. During informed consent, participants were told that they would be asked to complete a breathing task that may potentially produce some anxiety. To avoid priming participants with panic-related expectancies that might confound their baseline responses, they were informed that they would receive more information about the breathing procedure after completing these baseline measures. After completing a baseline SUDS rating, participants completed a battery of measures administered in randomized order. Next, participants were provided greater detail about the CO_2 challenge, including a full description of the steps involved in the procedure and the possibility of experiencing panic-related effects. Once participants consented to the breathing task, the experimenter attached the facemask and electrodes and re-administered the SUDS to obtain measures of anxious responding during the pre-CO_2 Anticipatory phase. Note, this phase occurred following attachment of the mask, a potentially anxiety-provoking stimulus in its own right, but prior to administration of the CO_2 gas. During the task, participants sat in a comfortable chair and breathed through a silicone facemask that covered their nose and mouth. The mask was connected via gas impermeable tubing to a two-way stopcock valve, allowing the experimenter to manually switch from room air to the CO_2 mixture. Once attached to the facemask, participants breathed regular room air for 5 minutes, followed by 8 minutes of 7.5 % CO_2 enriched air, followed by a 5-minute room air recovery before the mask was removed. The reservoir and stopcock valve were hidden behind a partition, and participants were not informed when the CO_2 enriched air was being turned on and off. SUDS ratings were then obtained once every two minutes throughout the CO_2 challenge task. Following the post-CO_2 Anticipatory phase, the facemask was removed. If participants' final SUDS rating was greater than 20 points above their baseline level, participants were given a deep breathing exercise to ensure that participants were not leaving the experiment feeling panicked. The description of these methods were adapted from Gorlin and colleagues (2014) and readers should consult this research study for more complete methods.

Measures

Anxiety Sensitivity Index. Prior to beginning the CO2 Challenge task, participants completed the Anxiety Sensitivity Index (ASI). The ASI (Reiss, Peterson, Gursky, & McNally, 1986) is a 16-item measure that assesses an individual's tendency to fear sensations or symptoms associated with anxiety (e.g., ‘‘It scares me when I become short of breath’’) on a 5-point Likert scale (0 = ‘‘Very little’’ to 4 = ‘‘Very much’’). This tendency is thought to reflect beliefs about the terrible consequences linked to anxiety symptoms. AS is considered a dispositional trait that increases fear and other anxious responding. The ASI is broken down into three lower-order factors: (1) fear of somatic symptoms, (2) fear of loss of cognitive control, and (3) fear of publicly observable anxiety symptoms (Zinbarg, Mohlman, & Hong, 1999). The scale has high internal consistency and good test–retest reliability (Peterson & Reiss, 1992).

Other instruments that were administered to participants include The Anxiety-Specific Attributions of Control scale—External Subscale (ASAC-Ext; Ginsburg and Drake, 1998) and The Diagnostic Symptom Questionnaire (DSQ; Sanderson et al., 1989) for Physical Panic Symptoms and (State) Threat Cognitions. However, they are not included in the current analyses and so will not be discussed further.

Heart Rate. All physiological data were collected using a Biopac data acquisition unit (Biopac Systems Inc., US). Heart rate was collected using a two-lead electrocardiogram (ECG) with lead placement on both wrists. The data were sampled at a rate of 1,000 Hz. Means of heart rate for each minute throughout the 18 minutes of breathing through the mask were calculated, and the minute of HR that followed each SUDS rating was used in the analyses. For example, the SUDS rating taken at minute two was paired with the HR from minute two to three, the SUDS rating at minute four was matched with the HR from minute four to five, etc.

Heart Rate Variability. HRV was calculated from the interbeat interval series using the Cardiac Metric (CMet) program. HRV was operationalized as the log of the variance of the IBI series (Allen, Chambers, & Towers, 2007). Data from the period before the CO2 gas was administered were used to create the measure of HRV.

Other physiological measures that were collected during this study but are not included in the current analyses so will not be discussed further include skin conductance (SC) and respiratory rate (RR).

Subjective Distress. The Subjective Units of Distress Scale (SUDS; Wolpe, 1969) is a verbally-administered rating scale used to index self-reported fear, on a scale ranging from 0 (no fear) to 100 (extreme fear). SUDS ratings were collected 11 times throughout the experiment to examine individuals' self-reported fear. SUDS ratings were taken twice before the CO2 gas mixture was administered. One was measured prior to the face mask and electrode placement, and the second was taken after the face mask and electrodes had been placed on the participant. The remaining nine SUDS ratings were taken at the end of every two minutes for the entirety of the CO2 challenge (e.g., 5 minutes of baseline breathing room air, 8 minutes of breathing 35% CO2 air, and 5 minutes of post-CO2 breathing room air). In order to examine how SUDS predicts HR within-subjects, SUDS ratings were paired with the average HR during the minute following the rating. For example, the SUDS rating taken after the mask had been placed on the participants corresponded to the first minute of HR, SUDS at minute two corresponds to the mean of minute three of HR, etc. Only these nine measures of SUDS were used in the current analyses.

Analytic Strategies

We analyzed a correlation matrix in order to determine the degree of concordance between HR and SUDS. This was calculated by identifying the highest SUDS for each subject and correlating that with each subjects' corresponding HR. This correlation was evaluated with a one-tailed test because we hypothesize that higher SUDS will correspond with higher HR, e.g., a positive correlation. If the correlation between maximum SUDS and the corresponding HR is positive and statistically significant, this will support the hypothesis that individuals' HR and SUDS are concordant.

Multilevel modeling is appropriate to use when participant data are nested within individuals. For our study, repeated measurements of HR and SUDS represent Level 1, and the differences at the individual level represent Level 2. Because repeated observations of HR and psychological distress (Level 1) were nested within individuals with different levels of AS and HRV (Level 2), multilevel modeling analyses were employed (Kahn, 2011). The analyses proceeded in three steps. In order to test our hypotheses, a series of multilevel models were run (see Results section for details) in HLM 7 (Raudenbush, Bryk, & Congdon, 2013). The likelihood-ratio difference test (Wilks, 1938) was run after each new model in order to determine whether the current model fit the data better than the previous one. A significant coefficient from the likelihood-ratio difference test at the appropriate χ^2 critical value, and a statistically significant *t* statistic indicates that our hypotheses related to synchrony were supported.

We used indices of effect size to quantify the degree to which AS and HRV predict concordance and synchrony between HR and SUDS. This was done by calculating ${R^2}_1$ and ${R^2}_2$ for Levels 1 and 2, respectively (Snijders & Bosker, 1994). These effect sizes allow us to analyze how our ability to predict HR stemming from individual sources is enhanced by including our predictors (SUDS, HR, and AS). This calculation was computed at each step of the model in order to see how much percent reduction in mean square error the addition of our predictor variables explain at Level 1 and Level 2 at each step of the model.

Results

Concordance Hypothesis (Hypothesis 1)

A correlation was calculated between the highest SUDS for each subject and the corresponding HR (see scatterplot; Figure 1). This is based on the definition of concordance provided by Rachman and Hodgson (1974), as the correlation between the two variables across subjects at a particular point. This correlation was evaluated with a one-tailed test because we hypothesized a positive correlation between higher SUDS and higher HR. The correlation relating HR and SUDS was positive, as expected, but not statistically significant $r(238) = .093$, though it approaches significance ($p<.08$) given the directional hypothesis. Thus there is no evidence in support of hypothesis 1 that there will be concordance between HR and SUDS.

Synchrony Hypotheses (Hypotheses 2-4)

All models are included in Table 1. Table 1 shows estimates, standard errors, and *t* statistics between the study variables.

An unconditional model was run in order to examine the amount of variance that is present within- and between-participants in order to determine whether MLM is appropriate to use. HR was specified as our outcome variable. This variance was calculated by dividing the between-group variance by the total variance. If there was at least some individual-level criterion variance, MLM was appropriate to use. We divided the variance between groups (97.87) by total variance (140.23). Thus, 97.87 / 140.23 = 0.697. This suggests that 69.7% of the variance in HR is present between individuals, and we have evidence for variance both within- and between-participants, and that MLM is appropriate to use. Additionally, this suggests that there is more variance in HR between individuals than within individuals.

Effect sizes were calculated after each step of the model in order to examine whether the current model fits the data better than the previous model and explains additional variance at Level 1 and Level 2. ${R^2}_1$ was calculated by summing the estimate of variance within-subjects (σ^2) and the estimate of variance between-subjects (τ_{00}) for the current model and dividing that by the sum of the estimate of variance within-subjects (σ^2) and the estimate of variance between-subjects (τ_{00}) for the previous model. This calculation was subtracted from 1 and corresponds to increase in percent of variance explained at Level 1 due to the addition of a new variable added to the current model at Level 1. ${R^2}_2$ was calculated by first dividing the estimate of variance within-subjects for the current model (σ^2) by n, which equals the number of Level 1 observations per subject. This number was added to the estimate of variance between-subjects (τ_{00}) for the current model. The denominator summed the estimate of variance within-subjects for the previous model (σ^2) divided by n and the estimate of variance between-subjects (τ_{00}) for the previous model. This number was then subtracted from 1 and provides an estimate that corresponds to increase in percent of variance in HR explained by including our Level 2 variables, AS and HRV, in our model.

In order to test our second hypothesis, a random coefficients (Model 2 in Table 1) model was run. Our Level 1 outcome was HR, and we entered SUDS. SUDS was entered person-mean centered because this centering strategy statistically controls for inter-individual differences that may affect individuals' HR (Enders & Tofighi, 2007). We then calculated the likelihood-ratio difference test in order to show this model fits the data better than the unconditional model (Wilks, 1938). The likelihood-ratio difference test was calculated by subtracting the "Deviance" of the second model from the "Deviance" of the unconditional model. Entry of SUDS yielded a statistically significant improvement in model fit, *difference of -2 log likelihood* = 1,146.89, *coefficient* = 0.15, *S.E.* = .01, *t* = 15.15, p < .01, ${R^2}_1$ = .05 and ${R^2}_2$ = .015. Since the *difference of -2 log likelihood* exceeded a χ^2 critical value of *d.f.*(1) = 3.84, we rejected the null hypothesis and inferred that the model that includes SUDS (Model 2) fits the data better than the model with no predictors (unconditional model). Because the *t* statistic for SUDS predicting HR is positive and statistically significant, we have evidence to suggest that SUDS is predictive of within-subject variance in HR over time. .05 corresponds to the amount of variance that is accounted for at Level 1 due to the addition of SUDS, and .015 corresponds to the amount of variance that is accounted for at Level 2 due to the addition of SUDS. This supports our second hypothesis that higher SUDS predicts higher HR within-subjects and provides evidence for synchrony between HR and SUDS.

In order to test the fit of our third model, AS and HRV were entered as predictors of the intercept. This model assumes that the slope between SUDS – HR is fixed across individuals (Culpepper & Aguinis, 2011) and provides information regarding between-subject variance in HR that is not accounted for by SUDS (Schwartz & Stone, 1998). Consistent with the recommendations of Aguinis and colleagues (2013), AS and HRV were entered as grand-mean centered predictors of HR. Entry of these predictors into the intercept equation did not yield a statistically significant improvement in model fit compared to Model 2, *difference of -2 log likelihood* = 4.01, ${R^2}_1$ = .0118 and ${R^2}_2$ = .016. The results for each of the predictors include, *coefficient* = .03, *S.E.* = .07, *t* = -.5, *p* = .62 for AS, *coefficient* = 1.83, *S.E.* = .74, *t* = -2.46, *p* = .015 for HRV, and *coefficient* = .15, *S.E.* = .01, *t* = 15.15, *p* < .01 for SUDS. Because the χ^2 value of *d.f.*(2) = 4.01 does not exceed the critical value = 5.99, this model overall did not fit the data better than the model that only included SUDS as a predictor of HR. However, HRV was statistically significant at $p < .05$. This suggests that HRV is predictive of inter-individual differences in HR (e.g., higher HRV corresponds to lower HR), but AS is not a significant predictor of HR.

To test our third and fourth hypotheses, we tested for slope variation in the HR–SUDS relationship across individuals. Freeing the slope (e.g., allowing the slope to vary across individuals; see Model 4 in Table 1) yielded a statistically significant improvement in model fit compared to the model that included HRV and AS as predictors of the intercept (Model 3), *difference of -2 log likelihood* = 72.25, p < .01, ${R^2}_1$ = .03 and ${R^2}_2$ = -.006, suggesting that the nature of the HR–SUDS relationship varied across individuals. Because we met this criterion, we then tested our cross-level interaction terms in order to examine whether there was greater synchrony between HR and SUDS for those who have higher AS (hypothesis 3) and higher baseline HRV (hypothesis 4). AS and HRV (grand-mean centered) were entered simultaneously as cross-level predictors of the slope and failed to yield a statistically significant improvement in model fit for AS, *difference of -2 log likelihood* = -16.23, *coefficient* = -.0002, *S.E.* = .002, *t* = -.10, *p* = .92, and HRV, *coefficient* = -.02, *S.E.* = .02, *t* = -.82, *p* = .41, ${R^2}_1$ = .08 and ${R^2}_2$ = .03 when compared to the model that allowed the slope to vary across individuals (Model 4). Because the coefficients for each predictor was very small, we do not have evidence to suggest that there is a stronger relationship between HR and SUDS for individuals who have higher AS or higher HRV, and thus there was no evidence that AS and HRV are individual differences that predict synchrony.

Discussion

Studies have long examined the relationship between self-reported emotion and physiology during emotional situations (Alpers & Sell, 2008; Campbell & Ehlert, 2012; Watson, et al., 1972). This study analyzed the relationship between HR and SUDS during a CO2 challenge and tested whether these variables were concordant and synchronous and whether AS and HRV predicted a synchronous relationship between HR and SUDS. Our study did not support hypothesis 1 of concordance between HR and SUDS, but did find that HR and SUDS were synchronous (hypothesis 2). Emotion theories (Darwin, 1872; Levenson, 1994) propose that emotion systems will exhibit synchrony as an individual responds adaptively to an emotion-inducing situation. Further, the literature has shown that when participants are instructed to modulate their responses, this instructed emotion regulation affects the relationship between self-report and physiology (Dan-Glauser & Gross, 2013; Gross, 1998). The results from these studies suggest that when examined, naturally occurring differences in emotion regulation (e.g., trait differences) may reliably affect synchrony in a similar way. The current study tested the effect individual differences have on synchrony, and found no evidence for either AS or HRV as predictors of a synchronous relationship between HR and SUDS (hypotheses 3 and 4). The following discussion reviews the literature, describes the implications of our study, and explores potential limitations and future directions for the synchrony/concordance literature.

Concordance (Hypothesis 1)

Our study did not find a statistically significant relationship between HR and SUDS, and thus failed to find evidence that the two are concordant. Our results fall in line with the mixed findings of the concordance literature (Barrett, 2006). Some studies have found concordance (Grossberg & Wilson, 1968; Lang, et al., 1970; Mauss et al., 2005), and a number of studies using the same parameters have not found concordance (Kamphuis & Telch, 2000; Öhman, 1987; Telch, Valentiner, Ilai, Petruzzi, & Hehmsoth, 2000). Although no studies to our knowledge have examined concordance using a CO2 challenge, concordance studies that used other biological and social stressors have, like our study, not found concordance. For example, Campbell and Ehlert (2012) conducted a review examining the relationship between physiology and self-report of participants during a social stressor. Of the 12 studies that examined the relationship between heart rate and self-reported emotion, only three studies showed a significant association between subjective stress and heart rate.

Hollenstein and Lanteigne (2014) contend that the components of the emotion system that are selected for tests of concordance are important. The authors suggest that associations between self-reported experience and behavioral expression have been the strongest, while pairings that include physiological variables have been the most inconsistent (Evers et al., 2014; Fischer & Roseman, 2007; Mauss, Levenson, McCarter, Wilhelm, & Gross, 2005). Further, Bulteel et al. (2014) argue that concordance is a “three-component process” (e.g., physiology, self-report, behavior) and solely using correlations for two components reflects “methodological limitations rather than a strong theoretical prediction that concordance should be bivariate”. However, even when studies examine all three, results show that self-reported emotion and facial behavioral indices were related but physiological response was not as strongly correlated when amusement and sadness were elicited (Mauss et al., 2005). This finding should be interpreted with the knowledge that behavioral indices are more personally perceptible than physiological measures, and thus allows behavioral measures to more easily affect self-reports; further, both self report and behavior are more susceptible to social influence. The results found by Mauss and colleagues (2005) lend support to the idea that concordance between self-report and behavior is more likely to be present because “externalized processes such as facial expressions are more obviously subject to forces of socialization…than are the internalized processes of visceral, humoral, or immunological responses" (Cacioppo, Uchino, et al., 1992, p. 110) and could explain why concordance is not always found when three response systems are measured.

Although most studies that examine the relationship between emotion systems hypothesize concordance between emotion systems, the bio-informational theory proposed by Lang (1979) argues that concordance should not necessarily be expected, because measures of self-report, physiology, and behavior are relatively independent entities. Friedman and colleagues (2014) state that the response for each subsystem (e.g., physiological, self-report, and behavioral) may not be activated simultaneously when accessing an emotional memory; thus concordance should not be expected. Lang (1979) proposes that how much of the network of an emotional memory is activated depends on the stimulus that is activating the network and on the strength of association between the propositions in the network. This can help explain the mixed findings in the concordance literature. Specifically, the seminal concordance studies that have found evidence for concordance have, for the most part, used a clinical sample and emotionally salient imagery for each participant (see Grossberg & Wilson, 1968; Lang, et al., 1970). It may be that concordance is less likely to be found in a non-clinical sample such as ours. The bioinformational theory is consistent with this conjecture in that it proposes concordance should be present when individuals experience strong emotions because subjective, behavioral, and physiological responses should align more closely (Cannon, 1927; Darwin, 1872; Grossberg & Wilson, 1968; James, 1884; Levenson, 1994).

Sze and colleagues (2010) provide an explanation for the inconsistent results found within the literature, and state that two very different methods have been used to assess concordance (Buck, 1980; Mauss et al., 2005). They indicate that most studies that examine emotion use a between-individual paradigm when a within-individual approach "…is much closer to the theoretical accounts…" of emotion and is a more favorable method to use when examining the relationship between emotion systems because these theories conceptualize "…coherence [of emotion] as the extent to which responses become coordinated with each other while the person is experiencing an emotion". Based on the rationale provided by Sze and colleagues (2010), we examined synchrony within-subjects for hypothesis 2.

Synchrony (Hypothesis 2)

Although our hypothesis related to concordance was not supported, the results supported the hypothesized effects related to synchrony: HR was higher within-subjects when SUDS ratings were also higher. This finding supports emotion theories that assert that emotional responses will be synced together over time (Grossberg & Wilson, 1968; Levenson, 1994) and provides support for the canonical fear response. Although not every study finds synchrony (Allen et al., 2015), and only approximately 20 studies have examined synchrony between emotion systems (Bulteel et al., 2014; Reisenzein, 2000; Sze et al., 2010), findings of synchrony are more evident in the literature than findings of concordance.

When studies have examined both synchrony and concordance, results show that synchrony is present and concordance is not. Alpers and Sell (2008) examined both the between- and within-subjects relationships in a study that included 36 self-reported measures of SUDS over six claustrophobia exposure sessions in a group of 10 participants with claustrophobia. The between-subjects analysis of heart rate and self-reported fear yielded non-significant small to medium size correlations, but the within-subject correlations were significant within and across sessions, indicating a synchronous change. Our results mirrored the results from this study despite employing a non-clinical sample, different emotion-eliciting situations, and a single session. This suggests that synchrony may be robust to different methods and samples even in contexts in which concordance is not found, and provides evidence that synchrony is more prevalent in the literature. Further, Butler and colleagues (2014) examined synchrony between three emotion systems and found that almost all of the variability occurred at the within-subjects level. The emotion regulation conditions that participants had been assigned explained a significant amount of variance, and the researchers reported no reason to continue their analyses to examine the between-subjects level because there was not enough additional variance to be explained between-subjects. This suggests that synchrony was present but concordance was not and supports the finding that synchrony may be a stronger indicator of emotion.

Reisenzein (2000) contends that a within-subjects approach examining synchrony is more appropriate because this method of analysis controls for "…factors that could in previous studies have lowered the correlations among the components…". The results from our second hypothesis support the notion proposed by Sze and colleagues (2010) that within-subjects approaches more closely represent the synchronization of emotion systems over time as an adaptive function, and that synchrony is a more robust index of emotion than concordance. A within-subjects analysis allows for individual differences and other factors to be accounted for, and the study described by Butler and colleagues (2014) provides evidence that individual differences affect synchrony.

Individual Differences Affecting Synchrony (Hypotheses 3 and 4)

Because the majority of studies in the synchrony literature have not examined individual differences, and Hollenstein and Lanteigne (2014) identified inclusion of individual differences as a reason to explain the mixed results in the literature, hypotheses 3 and 4 examined the effects that AS and HRV had on the relationship between HR and SUDS. Within-subjects analyses allow an indication of individual variation in the extent of synchrony, and this approach allows for examination of individual differences as predictors of that variability (Mauss et al., 2005). In our study, however, higher HRV and AS were not supported as significant predictors of a more synchronous relationship between HR and SUDS.

Hollenstein and Lanteigne (2014) highlight the need for studies to examine the effects of individual differences. However, most studies that examine individual differences thus far have focused on examination of instructed emotion regulation strategies, rather than naturally-occurring differences in individual traits. For example, Butler and colleagues (2014) tested the effects of two different forms of emotion regulation instructions (expressive suppression and positive reappraisal) on participants' subjective experience, expressive behavior, and physiology after watching an emotionally arousing film. The authors state that this analysis of synchrony picks up differences between-subjects, "…as well as variance due to shared momentary fluctuations, all of which reflect aspects of synchrony". When testing their variables, Butler and colleagues (2014) found that almost all of the variability occurred at the within-subjects level (e.g., the emotion regulation conditions explained significant variance at this level), and both expressive suppression and positive reappraisal resulted in greater synchrony between the emotion systems than the control condition. This study supports the notion that individual differences in emotion processing and regulation affect synchrony between emotion systems.

However, individual differences and how they affect one's reaction to stress-inducing stimuli may be better understood by examining trait differences and other individual differences that participants naturally exhibit (Hollenstein & Lanteigne, 2014) better than instructed regulatory conditions. For example, Rothbart and Rueda (2005) describe effortful control as a temperament construct that affects regulation. Individuals who are higher in effortful control may be better at controlling their emotional response across systems, and so may exhibit greater synchrony than another individual who is assigned to the same experimental condition. When studies do not account for individuals' natural tendencies and traits, important information regarding why one participant shows a more synchronous response than another assigned to the same condition is ignored. The only study to our knowledge to examine the effect of trait differences on synchrony is Peasley-Miklus and colleagues (2016). Based on the literature examining AS and HRV, we hypothesized that higher levels of our trait differences of AS and HRV would predict a synchronous relationship between HR and SUDS.

Anxiety Sensitivity. We hypothesized that higher AS would predict greater synchrony between HR and SUDS because the interoceptive sensitivity hypothesis states that "…nonclinical high AS individuals are characterized by an enhanced ability to accurately detect arousal-related bodily sensations" (Stewart et al., 2001, p. 537), and individuals with increased anxiety sensitivity will experience arousal-related somatic sensations and respond with anxiety (Ehlers, 1993). Stewart and colleagues (2001) examined the effects of anxiety sensitivity on heartbeat awareness and heart rate reactivity in a nonclinical sample. The authors hypothesized that individuals with high AS would be more aware of their heartbeat compared with the low AS group. Results showed that there were no differences in heart rate reactivity between the two groups, but the high AS group was significantly more accurate in predicting their actual heart rates, supporting the interoceptive sensitivity hypothesis. Sturges and Goetsch (1996) report that individuals who are more fearful of interoceptive symptoms are likely to be more motivated to monitor these symptoms. Based on this study, we hypothesized that individuals with higher AS would show synchrony between HR and SUDS because they would be monitoring their HR more closely and would self-report more distress to match higher HR.

Our results did not support our hypothesis. A potential explanation for the lack of significance of AS in predicting synchrony between HR and SUDS could be that individuals with high AS may be able to detect their sensations but have difficulty verbalizing their distress level (e.g., SUDS). Research suggests that there is a positive relationship between high AS and alexithymia within a nonclinical sample (Devine, Stewart, & Watt, 1999). Specifically, the ASI scores in this sample were most strongly correlated with difficulty identifying and describing emotions. A study conducted by Peasley-Miklus and colleagues (2016) assessed the relationship between physiology and self-report when participants varying in alexithymic traits imagined emotion-eliciting scripts. Alexithymia includes difficulties in identifying and communicating feelings, and desynchrony found between emotion systems in individuals with more alexithymic traits suggests poor emotion regulation (Connelly & Denney, 2007). The hypothesis proposed by Peasley-Miklus and colleagues (2016) was supported and they found evidence for desynchrony because the relationship between arousal and heart rate during emotional imagery was weaker as alexithymia increased. Zeitlin and McNally (1993) propose that individuals with higher AS may suppress their emotions as a means to avoid the feared anxiety-related somatic sensations. The authors further suggest that emotion suppression by high AS individuals may make expression of emotions difficult because they may be unwilling to describe their emotions for fear of triggering anxiety-related bodily sensations (Zeitlin & McNally, 1993). Based on these findings, it may be expected that individuals with higher AS should not show synchrony between emotion systems because these individuals have difficulty identifying and describing emotions and will show a similar pattern of response as those with alexithymia (Peasley-Miklus et al., 2016). The desynchrony found between self-report and heart rate in this study provides evidence in support of Peasley-Miklus and colleagues (2016) that those with emotion regulation deficits respond desynchronously to a stress-inducing situation.

Heart Rate Variability. We hypothesized that higher HRV would predict synchrony between HR and SUDS because "individuals with low HRV have increased difficulties in emotion regulation in contexts requiring it" (Porges, 2007, p. 118), and individuals with higher HRV and better emotion regulation and will respond more adaptively than an individual with lower HRV. Emotion regulation should be related to synchrony because emotion regulation is defined as "…the process by which one influences how, when, to what degree, and which emotions he or she experiences and expresses" (Gross, 2002, p. 282). Those with better emotion regulation may be able to control their self-reported emotion and physiology more adaptively than those with low emotion regulation in a way that meets the demands of the situation. An adaptive response would presumably involve a synchronous response from emotion systems.

Our results did not support our hypothesis: HRV was not a significant predictor of synchrony between HR and SUDS. The non-significant results should be interpreted with caution because HRV was calculated from the period immediately after participants had been told that they might experience anxiogenic effects from the CO_2 inhalation (see Gorlin et al., 2014). This could have affected HRV because when participants heard the instructions for the CO_2 challenge, they may have been primed to experience an increase in anxiety before the CO_2 air began flowing. This may have limited the power of HRV to predict synchrony. Thayer, Friedman, and Borkovec (1996) examined HRV in a sample of individuals with GAD and non-clinical participants over three different periods: baseline, relaxation, and worry. Their results showed that there were significant differences between groups across all periods, but most interestingly, during the period when GAD participants were told to worry, their HRV decreased significantly compared with the control group. These results pertain to our study in that participants may have exhibited differential HRV responses to the initial CO2 challenge instructions, biasing our trait HRV measure. Individuals with lower HRV are likely to be characterized by more anxiety and be more prone to worrying (Thayer et al., 1996), so hearing the experimental instructions may have induced greater anticipatory anxiety within this sample. Thayer and Lane (2000) provide evidence that those with low vagal tone (e.g., HRV) are more biased to appraise threat in their environment. This in turn may have made the low-HRV group pay even more attention to the threatening stimuli, and these individuals were then less able to shift their attention and adapt effectively. This would result in less synchrony because these individuals would not be responding to the CO2 challenge adaptively, and an adaptive response would involve synchrony of emotion systems (Porges, 2007).

In light of our study's findings, studies that have examined HRV as an individual difference in predicting avoidance (Katahira, Jujimara, Matsuda, Okanoya, & Okada, 2014) and thought suppression (Gillie, Vasey, & Thayer, 2015) have found that higher HRV was related to more positive outcomes and both of these studies were able to use an unbiased measure of HRV. We expect HRV to be related to synchrony because high HRV is a measure of adaptive emotion regulation in contexts that require it (Gross, 2002), and adaptive functioning during emotion-inducing situations involves a synchronous coordination of emotion systems. HRV should be further examined as an individual trait difference based on the results found in other studies that calculated HRV from a time period where participants were not primed to preemptively experience anxiety.

Limitations and Future Directions

The present study should be interpreted in light of several limitations. The use of secondary data greatly limits the flexibility and hypotheses that this study could have made. Individual differences that have been shown to affect the relationship between emotion systems in the literature (e.g., physical fitness, respiratory health) were not included in the original study that our data came from. Other individual differences that may likely affect the synchrony between HR and SUDS still need to be investigated.

Future research examining the relationship between emotion systems should incorporate the suggestions made by Hollenstein and Lanteigne (2014). Specifically, studies should include examination of individual differences and use within-subjects analyses. Our study is one of few to examine both synchrony and concordance within the same study and is the second study (Butler et al., 2014) to our knowledge to use multilevel modeling, a powerful approach to examining within-subjects effects. Further, studies have shown that when researchers account for factors such as respiratory health and emotion regulatory strategies (Butler et al., 2014; Dan-Glauser & Gross, 2013; Gross, 1998; Salmon, 2001), differences between subjects in these variables affect the degree of synchrony between self-report and physiology. Future studies should use a multilevel modeling approach for examining repeated measures because this technique provides more information regarding the relationship between HR and SUDS than using bivariate correlations at one point in times. Specifically, within-subjects analyses “are helpful to identify the meaningful covariation of different measures across time” (Alpers & Sell, 2008).

Following our study, a number of questions remain unanswered. The literature uses a number of different methodologies and analyses that vary greatly between studies. Additionally, there is not a consistent method for measuring synchrony and concordance, and studies often use poor measurement strategies. For example, in their review of 49 studies examining the relationship between physiology and subjective experience of emotion, Campbell and Ehlert (2012) report that in 58% of the studies they included in their review, self-report of emotional state were either collected both pre- and post-stressor or only a single assessment post-stressor. This method limits the data that are available and can be greatly influenced by retrospective bias.

We suggest that the specific definitions of synchrony and concordance should be adopted as measures of within- and between-subjects effects, and that the relationship of emotion systems over time should be used consistently and defined as synchrony. This will benefit the literature because it will allow researchers to have a more consistent language to describe studies and draw comparisons between studies. In our review of the literature, discordance, concordance, and no relationship were found for different correlations between emotion systems across studies. Using within-subjects analyses that analyze emotion systems relationships over time, identifying individual differences that may affect this relationship, and creating a consistent standard that is used across studies will potentially result in a greater understanding of emotion because it will provide the field with information regarding the types of emotions and specific factors that result in greater synchrony. In order for the field to advance, synchrony and within-subjects analyses should be measured more consistently in studies because these methods allow for the examination of emotion in the sense that theories have proposed that emotion operates.

Conclusion

This study is one of the first to examine both synchrony and concordance within the same study, and it suggests the importance of conducting both within- and between-subjects analyses because they provide different information about the relationship between emotion systems. In studies that have examined both synchrony and concordance (Alpers & Sell, 2008; Butler et al., 2014), results show that synchrony is present and concordance is not. Our results are in line with these findings and provide evidence that synchrony is a more powerful index of emotion and should be examined in future research when the relationship between emotion systems is analyzed. As Sze and colleagues (2010) have stated, synchrony may be a more robust index of emotion because it allows for the examination of the relationship of emotion systems over time.

Although our findings from this study did not support all of our hypotheses, our study is one of few that examines both synchrony and concordance within the same study, uses a within-subjects analysis over time, and seeks to examine how individual differences affect synchrony. The results support claims that concordance does not fully represent the nature of emotion because concordance does not examine how these relationships change over time (Sze et al., 2010). Explanations in support of synchrony emphasize the inclusion of individual differences and use of within-subjects analyses (Hollenstein & Lanteigne, 2014). Our review of the literature suggests that examination of individual differences and using within-subjects analyses such as multilevel modeling will provide researchers with a better understanding of how emotion changes over time and the way that differences can affect this relationship. The field will benefit tremendously by including individual differences in their analyses and using within-subjects analyses as a means to examine the synchrony of emotion systems, and in doing so, may disentangle this mixed literature.

Appendix

Table 1. Models predicting HR from Level-1 predictor SUDS and Level-2 predictors HRV and AS

Variable	Unconditional	Model 2	Model 3	Model 4	Model 5
	Coefficient *SE* *t*	Coefficient *SE* *t*	Coefficient *SE* *t*	Coefficient *SE* *t*	Coefficient *SE* *t*
Level 1					
Intercept (γ_{00})	79.06** (.60) 131.09	78.84** (.60) 131.53	8.85** (.59) 132.55		78.85** (.59) 132.59
SUDS (γ_{10})		0.15** (.01) 15.15	.15** (.01) 15.15	.17** (.02) 10.43	.17** (.02) 10.42
Level 2					
Heart Rate Variability (HRV) (γ_{01})			-1.83* (.74) -2.46	-1.79* (.74) -2.41	-.0002 (.002) -.1
Anxiety Sensitivity (AS) (γ_{02})			.03 (.07) -.50	-.03 (.07) -.50	-.02 (.02) -.1
Variance components					
Within-person variance (σ_2)	42.36	37.46	37.46	33.12	33.13
Intercept variance (τ_{00})	97.87	96.41	94.83	95.45	95.45
Additional information					
- 2 log likelihood		1146.89	4.01	72.25	-16.23
R^2_1		.05	.012	.03	.08
R^2_2		.015	.016	-.01	.03

*p < 0.05.
**p < 0.01.

Figure 1. Participants' highest SUDS rating and its associated HR

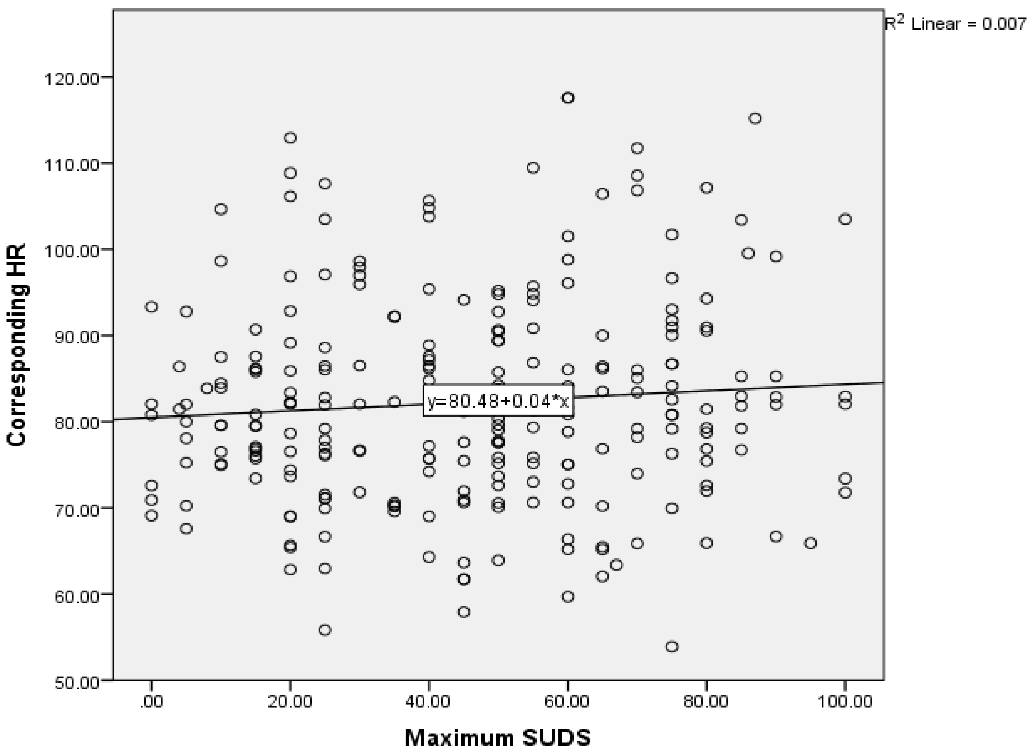

Table 2. Descriptive Statistics for our Level 1 and Level 2 variables.

Descriptive Statistics

	N	Range	Minimum	Maximum	Mean	Std. Deviation
HR	2698	86.86	59.47	146.33	80.2804	11.46128
SUDS	2983	100.00	.00	100.00	25.9665	22.59657
ASI	298	60	0	60	17.95	9.073
HRV	291	5.39	5.34	10.73	8.3848	.79621
Valid N (listwise)	210					

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