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Teams under stress: Social and physiological processes facilitating teamwork

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The Dissertation of Yumeng Gu is approved, and it is acceptable in quality and form for publication on microfilm and electronically.

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DEDICATION

This dissertation is dedicated to my parents and best friends Wei Gu and Xiaoling Jiang, who have always been my source of inspiration and strength. Thank you for blessing me with a loving family to grow up in and to go back to.

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EPIGRAPH

"Coming together is a beginning, keeping together is progress, working together is success."
----*Henry Ford*

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ABSTRACT OF THE DISSERTATION

Teams under stress: Social and physiological processes facilitating teamwork

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Team performance contexts are ubiquitous and stressful. From group projects in educational settings to cross-functional projects in organizations, teams are presented with acute task demands. Traditionally, team research has relied on after-the-fact subjective self-reports and archival data. And little is known about the social processes in teams, including the role of emotion expression and coregulation in the face of acute stressors. The goals of this dissertation are to use ecologically valid paradigms that 1) provide new methodological advances for studying the social processes in teams using relatively non-invasive physiological measures that assess physiological stress and can serve as an index of team coordination and 2) expand the current literature on gratitude expression and emotion regulation to team contexts, especially those under stress.

Studies in the current dissertation are some of the first to empirically investigate social processes in teams using a novel paradigm and physiological approach. Findings from these studies highlight the importance of emotion in teams in that emotion expression (e.g.: gratitude expression in Chapter 1) and a lack of emotion expression (Chapter 2) would affect both members of a dyadic team, indicating the social consequences of emotion expression and emotion regulation in teams. These studies also provide new insights of when teams work *together* and *individually.* Remarkably, this dissertation reports some of the first studies to use physiological measurements, including cardiovascular efficiency and physiological linkage between teammates, to study stress response and coordination between teammates. These findings in dyads add new angles and methods of investigating biological and behavioral consequences of emotion expression and emotion regulation between teammates, which may not easily be assessed otherwise. Taken together, the current dissertation will bring significant advances to the broad field of social psychology, organizational behavior, and medicine. In addition, findings in this dissertation have important implementation on optimizing intra- and interpersonal consequences in teamwork under stress.

Introduction

Teams are ubiquitous and important in everyday life, and modern organizations, in particular, rely on teams (Edmondson, 2012; Mathieu et al., 2014). From group projects in educational settings to cross-functional projects in organizations, teams are presented with acute task demands (e.g., completing a project in school or finalizing a marketing plan for a technical device in the workplace). Teams are different from other social groups in that there is an interdependency between the members of teams. Therefore, it is important to understand team dynamics, optimize teamwork and conduct research in team contexts. Teams are complex because members interact and cooperate in order to accomplish tasks, complete projects with limited resources, and produce optimal results under time and social evaluation pressures. Although the stream of research on teams can be traced to the Hawthorne studies back in the 1920s and 1930s, team research only gained traction since the 1990s. While most research focused on team member's characteristics and composition, the role of social and physiological processes in teams remains unclear. Specifically, previous literature has found that individuals frequently seek to regulate their affective responses by changing cognitive processes (Gross, 2002), adopting a self-distanced perspective (Ayduk & Kross, 2010), or later appraisal of physiological responses (Jamieson, et al, 2018). It is, however, unclear how these intrapersonal efforts transmit between teammates, which holds important implementations and interventions such as understanding team dynamics and team coordination, promoting health, emotion and physical well-being.

Social processes in teams

One way to assess social processes in teams and its downstream outcome is to investigate emotions in teams. A traditional view of emotion suggests that emotions cloud judgment (Le

Bon, 1895). However, contemporary researchers have demonstrated that emotions serve key social functions that help group members address various problems with living and working in groups, such as the development and maintenance of group cohesion (e.g., Keltner & Gross, 1999; Frijda & Mesquita, 1994). Emotions are usually expressed to others and regulated to influence others (Van Kleef, 2009, Fischer & Manstead, 2016). Despite these developments, the impact of individual emotions on team dynamics, cohesion, and adaptation to stress still remain to be explored. Therefore, by investigating the role of emotion in teams, we can answer important questions such as what different emotion expressions, such as positive emotion expression, can do for teams, and how a lack of emotion expression, i.e.: emotional suppression, would impact teammates. Understanding how these social processes help optimize stress in team settings is critical for multiple fields, including social psychology, organizational behavior, and medicine. It could enable us to derive translatable strategies to mitigate stress in teams, improve team performance and cohesion, and secure long-term well-being and health of team members. One goal of this dissertation, therefore, is to provide a deeper understanding of the social processes in teams by studying the role of emotions in teams using ecologically valid dyadic teamwork paradigms and to establish some of the first empirical studies directly investigating the relationship between social and physiological processes in teams.

Emotion expression

Emotions are affectively charged states that help people respond to specific problems and opportunities (Nesse, 1990; Keltner & Haidt, 1999; Keltner & Lerner, 2010). While social psychologists have multiple, competing theories that define emotion differently, which is beyond the scope of this dissertation, many theories agrees that emotions are different from moods and traits in that emotions are briefer, more context specific and more focused on a particular cause or salient objects (Ekman, 1992; Schwarz, 1990; Clore & Colcombe, 2003; also see review in Keltner & Lerner, 2010).

This dissertation focuses on the *social* functions of emotions. Most emotion research has focused on the intrapersonal functions of emotions. Emotions involve the association of a person's appraisal, experiential, behavioral and physiological response (Mauss et al., 2005). However, emotions are also inherently social -- they tend to be elicited by others, expressed toward others, and regulated to comply with social norms or influence others (Van Kleef et al., 2016, Parkinson, 1996; Van Kleef, 2009; Fischer & Manstead, 2016; Keltner & Haidt, 2001). Previous literature has shown that at a dyadic (two people pair) level, researchers have focused on the role emotions play in interactions within meaningful relationships. The conscious feeling of emotion informs individuals about their condition and problems (Campos et al., 1989), evokes reciprocal emotions, and incentivizes or deters others' social behavior (Keltner & Haidt, 1999). For example, expression of anger signals that someone else was responsible for an adverse situation, whereas expression of regret evokes inferences that the expresser was responsible (Van Dorn et al., 2015). However, little is known about how emotion expression, especially positive emotion expression, influences stress coping among teammates. In particular, it is possible that a relationship-building emotion, such as gratitude, can facilitate resilience during a stressful task.

Emotion regulation

Since emotion expression conveys information for those around us, we sometimes want to influence which emotions we have and how we want to experience and express them. This process is referred to as emotion regulation. Experienced emotion can be regulated by changing the underlying antecedent psychological, physiological, and situational mechanisms occurring upstream (Gross, 2002). Oftentimes, regulation states are implemented after emotions have been experienced, and the most common regulation strategy that is response-focused is suppression. Suppression is thought to inhibit ongoing emotion-expressive behavior, therefore, emotional suppression researchers mainly found that suppression is effortful and doesn't alter felt affect (Gross & Levenson, 1997; Harris, 2001). Physiologically, suppression has been shown to be associated with increased sympathetic activation of the cardiovascular system and less efficient cardiovascular response (Gross & Levenson, 1993, 1997). People who chronically suppress ruminate more about their negative mood and the self (Gross & John, 2003). Suppression research mainly focused on its intrapersonal effects, with less attention to its social consequences, which results in a lack of knowledge on how emotional suppression impacts teamwork.

Importance of understanding physiological processes in teams

Much empirical team research has been static rather than dynamic, assessing how team states rather than team dynamics are related to outcomes such as team stress and coordination (see review Kolbe & Boos, 2019). Thus, teamwork studies have relied on self reports and archival data to study teams. A growing body of literature in affective science suggests that another way to investigate the role of emotion on individuals and groups is through physiological processes (e.g.: Mauss & Robinson, 2009; Ekman, Levenson & Friesen, 1983). Physiological approaches have been often used to capture psychological experiences of individuals since the early 20th century (e.g.: Darrow, 1929). One strength of studying physiological influence of emotion in interpersonal interactions is that it allows researchers to test theoretical questions that aren't testable using traditional methods such as self-report or behavioral coding (Thorson et al., 2018). In particular, physiological measures allow researchers to measure psychological processes that are outside of awareness and may not be readily observable without disrupting the natural dynamics of an interaction (Thorson et al., 2018). In this work, I focus on two frameworks in which understanding physiological processes provide new insights about social processes in teams, such as teammates' stress response and team coordination.

Biopsychosocial (BPS) model

Physiological responses can assess teammates' stress objectively in a team setting. One example is the study of physiological response to stress. The biopsychosocial model (BPS) of challenge and threat (Blascovich, 2008; Blascovich & Mendes, 2010), for example, is a well validated theoretical model that examines neuroendocrine-driven patterns of cardiovascular responses. Challenge and threat responses are associated with specific patterns of physiological reactivity, which are used to assess stress response *in vivo* during acutely demanding tasks (e.g.: Hangen, Elliot & Jamieson, 2019; Jamieson & Mendes, 2016). Scholarship on stress response in individuals provides a theoretical frame for understanding the interplay between cognitive, physiological, and motivational processes underlying stress response in acutely stressful contexts (for review, see Blascovich & Mendes, 2010; Jamieson et al., 2018; Oveis et al., 2020). And challenge and threat responses lead to important short- and long-term consequences within individuals. For example, in short-term, threat impairs decision-making (Kassam et al., 2009) and diverts individuals from opportunities for growth (e.g.: Crum et al., 2013). In the long term, repeated threat response can lead to cardiovascular diseases and reduced immune and cognitive functions (e.g.: Jefferson et al., 2010; Lundberg, 2005; Matthews, Gump, Block, & Allen, 1997;

for review, also see Oveis et al., 2020). Therefore, using challenge and threat responses to assess stress response in teammates can provide a more comprehensive understanding of stress in teams, and how social processes can influence teammates' response to stress in motivated tasks.

Physiological linkage

Physiological responses not only are used to assess psychological processes within an individual, they are also key for assessing interpersonal interactions that can lead to novel insight regarding to interpersonal dynamics, and how people can "catch" others' emotions and how emotions "spread" (Thorson et al., 2018; Levenson & Ruef, 1992; Hatfield et al., 1994). Many theoretical and empirical papers have highlighted what psychological processes one can assess by examining the similarities in partners' physiological states (e.g., Butler, 2011; Levenson & Ruef, 1992; Waters, West & Mendes, 2014). There is a growing interest in studying shared physiological experiences in social interaction to assess different psychological processes (e.g.: Sbarra & Hazan, 2008; Waters, West & Mendes, 2014; see Palumbo et al., 2016; Timmons et al., 2015, and Thorson et al., 2018). The similarity between partners' physiological responses that occur at the same time point, or physiological linkage, synchrony, or coregulation, is associated with psychosocial processes that occur between partners and indicates interpersonal processes, such as shared emotion states, other-oriented social engagement, aspects of social well-being (Oveis et al., 2009; Butler, 2011; Geisler, Kubiak, Siewert, & Weber, 2013).

For the reasons above, a goal of this work is to build on existing literature of the BPS model and physiological linkage to provide some of the first empirical studies to expand the context of current psychophysiology literature to how teammates respond and coordinate under acutely demanding stress tasks.

Current dissertation

While much research has investigated how to optimize teamwork and team coordination, little is known about 1) the effect of emotional expressions on teammates' stress response, especially those with loose-tie relationships, and 2) whether and how intrapersonal emotion regulation strategies might influence how *teams* respond under stress. Building on existing literature on the social function of emotion and emotion regulation, the current dissertation examines the role of emotion expression in team settings and explores its downstream outcomes. Specifically, I intend to answer the questions: does emotion expression, such as gratitude expression, influence teammates' stress response? Does emotion regulation effort within a teammate influence their teammate?

The current dissertation makes several contributions. Overall, it fills in the gap in the literature by investigating a) whether the expression of gratitude, a relationship facilitating emotion, would improve teammates' stress responses during teamwork (Chapter 1) and b) whether a lack of emotion expression (i.e., suppressing one's emotional expressions) would disrupt teammates' physiological coordination during different team settings, such as during collaboration and individual performance (Chapter 2). Answering these questions will have important downstream consequences and implementations such as injecting gratitude into workplaces to help teams cope with stress, assessing team dynamics and social connectedness, and developing interventions to promote emotional and physiological well-being in teams.

Chapter 1 advanced the current research on gratitude expression in that it is the first study to look at biological consequences of gratitude expression between teammates with loose-tie relationships. While previous literature on gratitude focuses on stranger pairs or romantic partners, this chapter extended it to loose-tie relationships. In addition, this is also the first study to directly investigate biological consequences of gratitude expression using well-validated physiological measures that reflect stress response efficiencies of teammates under stress. The findings not only suggest that gratitude expression can promote biological stress response during motivated teamwork, but also have important implementations in teams and organizations in real life, and in ongoing relationships of everyday life, more generally.

Chapter 2 made important contributions in both emotion regulation and psychophysiology because it's one of the first studies to demonstrate the existence of parasympathetic linkage between teammates during different teamwork contexts. Previous emotion regulation research focus on intrapersonal effect of emotion regulation, i.e.: how an individual's regulatory efforts influence themselves. This chapter intended to investigate whether intrapersonal emotion regulation could have an impact on others through the lens of physiological linkage, a well-validated physiological process shown to indicate social engagement and social connectedness. In addition, this chapter also intended to answer deeper questions: 1) when physiological linkage occurs during complex teamwork settings, and 2) what different emotion regulation strategies

In addition, the current dissertation makes methodological contributions by using novel and ecologically valid methods to study loose-tie relationships and stranger teammates under stress. Furthermore, the current dissertation uses well-validated biological measures that reflect stress response efficiency and autonomic coordination to determine consequences of social processes in teams. The current dissertation advanced psychophysiology literature in that the studies presented are some of the first to examine physiological stress response and parasympathetic synchrony in team contexts.

These specific biological outcomes in dyads are critically relevant to the study of stressful teamwork in motivated performance tasks, and interpersonal dynamics in teams. *The first line of research demonstrates that manipulating one teammate to express gratitude to another teammate improves physiological stress responses in the dyad while they engage in stressful teamwork. The second line of research demonstrates that manipulating a teammate to suppress emotional expressions renders physiological linkage between teammates nonsignificant during collaborative work, whereas a different form of emotion regulation (reappraisal) and a no instruction control condition preserve physiological coordination between the teammates.* Overall, this dissertation aims to provide new angles and methods to characterize social processes in teams and the impact of emotions on teamwork and performance under stress.

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Chapter 1

Gratitude expressions improve teammates' cardiovascular stress responses

1.1 Introduction

1.1.1 Overview

Over the past 15 years, the accumulation of evidence for the central and largely beneficial role of the emotion of gratitude in social life has accelerated across psychological and organizational sciences. Researchers have documented that gratitude influences a wide variety of behavioral and phenomenological outcomes, such as affiliative behavior, perceptions of partner responsiveness, and personal and relational well-being, largely examining these effects between romantic partners or strangers (see Algoe, 2012, 2019). Despite this ever-growing body of evidence, two important areas of inquiry have been relatively neglected: the interpersonal dynamics of gratitude between loose ties, like acquaintances or co-workers, and the potentially beneficial ways that these dynamics influence biological outcomes when members of the dyad interact. Here, we contribute substantially in these two domains by experimentally manipulating gratitude between loose-tie teammate dyads, and testing the teammates' *in vivo* stress responses during ecologically valid stressful teamwork.

Building on a substantial body of evidence that the momentary emotional response of gratitude to another person for their kind actions helps promote a high-quality, communal relationship between the grateful person and their benefactor (see review in Algoe, 2012), many researchers have focused on *expressed gratitude* as a behavioral mechanism that facilitates that dyadic process (e.g., Williams & Bartlett, 2015). One nice feature of this rapidly expanding body of literature is that the evidence often comes from studies involving both members of the dyad (e.g., Algoe, Fredrickson, & Gable, 2013; Brady et al., 2020; Leong et al., 2020; Park et al., 2019); as one example, couples randomly assigned to express gratitude to one another over a month-long period reported greater daily adaptation to change as well as positive mood compared to couples in a control condition (Algoe & Zhaoyang, 2016). At the same time, most of these data come from just one type of relationship that is important to everyday life—romantic—whereas other important types of relationships deserve increased attention.

The present work focuses on the *dyadic* consequences of gratitude expressed between members of loose-tie relationships (university suitemates) working together on a stressful motivated performance task conducted under time- and social evaluative-pressure. This research holds meaningful implications for organizations, and particularly teams, which involve loose ties who often work together under acutely stressful conditions to accomplish joint goals. Gratitude expressions within work environments may be a key to building relationships, binding together teammates, and potentially making joint tasks seem less threatening. And in building relationships, gratitude expressions could promote more efficient team stress responses by enhance perceived personal or social resources or by decreasing the perceived demands of stressful tasks. Consistent with this view, for example, thinking of a supportive friend caused individuals to perceive their environment as less demanding and view challenges in a more moderate way (Schnall et al., 2008). People spend a third or more of their daily lives at work; thus, understanding how gratitude can shape stress responding during teamwork is a critical topic of examination. But, thus far, no dyadic data exist to test these propositions; the present research addresses them directly.

1.1.2 Gratitude expressions and challenge/threat responses

A second critical advance of this research is examining the *biological* consequences of expressed gratitude. Our approach is guided by the biopsychosocial (BPS) model of challenge and threat, which provides a framework for understanding how appraisal processes impact responses to acute stress (for reviews, see Blascovich & Mendes, 2010; Jamieson et al., 2013; Mendes & Park, 2014). When people appraise that the demands of a task exceed their own resources to complete the task, they are likely to experience a *threat* response, marked by less efficient cardiovascular activation. In contrast, when people appraise that their resources exceed the demands of the task, they are likely to experience a *challenge* response, marked by more efficient cardiovascular activation. The BPS model of challenge and threat specifies the underlying psychological mechanisms of stress responses in performance contexts. Specifically, the psychological mechanism underlying the BPS model is the perceptions of "demands" and "resources". Demands consist of perception of uncertainty, danger, and/or effort. Motivated performance situations, such as group projects, are stressful in that they contain important yet uncertain consequences.

Determining whether gratitude expressions impact challenge and threat responses is important because of the focal connection between challenge and threat responding and the quality of task performance (e.g.: Moore et al., 2012; Seery et al., 2010), and because physiological patterns of challenge and threat have important downstream consequences. For example, threat responses impair decision making (Kassam et al., 2019), whereas challenge responses are associated with better performance in cognitive and motor tasks (Turner et al., 2012). Over the long term, threat responses are associated with elevated risk for cardiovascular disease, less effective immune response, and cognitive ability impairments (e.g., Jefferson et al., 2010; Matthews et al., 1997). Moreover, challenge and threat responses have been used to conceptualize and assess resilience—defined as adaptation to potentially stressful experiences—during acute and mundane stressors (Seery, 2011, 2013).

Importantly, patterns of challenge and threat can be reliably assessed in biological measures (Blascovich & Tomaka, 1996; Blascovich & Mendes, 2000). Threat responses are marked by less efficient cardiovascular activation observed in two key outcomes: decreased cardiac output (CO; i.e., amount of oxygenated blood pumped from the heart to the periphery) and increased total peripheral resistance (TPR; i.e., constriction of the vasculature). Challenge response, in contrast, are marked by more efficient cardiovascular activation observed in increased CO and decreased TPR. In the present work, we focus on these gold standard biological measures of cardiovascular efficiency to determine how gratitude impacts teams under acutely stressful conditions. These specific biological outcomes in dyads are critically relevant to the study of stressful teamwork in motivated performance tasks. Understanding how gratitude can impact individuals' and teams' challenge and threat stress responses hold implications for literatures examining factors that can mitigate harmful stress responses, across a variety of disciplines.

The present study advances the literature on gratitude with novel contributions. In research with *individuals*, few studies have found physiological consequences of gratitude—on markers of inflammation and heart rate variability (Redwine et al., 2016), and on arousal (Drążkowski, Kaczmarek, & Kashdan, 2017). Critically, both used gratitude journaling paradigms rather than gratitude expression; neither investigated stress-related physiological responses or used a dyadic paradigm. Only one correlational work has demonstrated an association between individuals' state gratitude and systolic blood pressure reactivity (Ginty et al., 2020). For the first time, the present research examines the dyadic consequences of gratitude expression on stress-relevant physiological responses during ecologically valid stress tasks. It represents a leap forward in our understanding of the potential implications of gratitude in teamwork specifically, and in ongoing relationships of everyday life, more generally.

1.1.3 Current research

The present study examines the dyadic, biological consequences of gratitude expressed between people in a loose-tie relationship. After one member is randomly assigned to a gratitude or neutral expression, partners complete a stressful, ecologically valid teamwork paradigm involving two sequential tasks: a collaborative work task (to assess effects when partners are actively working together) and an individual performance task (to assess whether effects persist after the partners are no longer actively interacting). We predicted that gratitude expressions, which have been shown to build relationships, would promote challenge-type physiological responses in teams. Due to gratitude's dyadic interpersonal consequences (Algoe & Zhaoyang, 2016), we had no expectation of differences between expressers and receivers, so we analyzed the data focusing on the dyadic-level condition effect on individuals, using multilevel models.

1.2 Methods

Sample size determination. An *a priori* power analysis was used to determine sample size. There is no previous research investigating gratitude and challenge and threat physiological measurement. Therefore, we based our power analysis on previous work on challenge and threat responses with *in vivo* cardiovascular measures in dyads (Peters et al., 2014), suggesting an anticipated effect size of d = 0.59. Given the complexity of estimating power for multilevel analysis, we more conservatively used effect size of d = 0.5. In Optimal Design Software (Raudenbush et al., 2011), an a priori power analysis determined that 75 dyads would be necessary to achieve 0.8 power. Anticipating the potential for data loss, we decided to recruit 100 dyads.

Participants. Two hundred undergraduates from the University of California, San Diego participated in dyads, receiving $24 each as a part of a larger study on gratitude expressions (Study approved by the UCSD Human Research Protections Program under Project 151219S). Each dyad consisted of same-gender, first-year students who had been living together as suitemates for approximately four months. Ten participants were excluded due to unusable physiological data and two were excluded due to experimenter error. The final sample (N = 190; 144 women, 46 men; M_{age} = 18.1, SD_{age} = 1.10, Range = 18-20; 112 Asian/Asian-American/Pacific Islander, 20 Hispanic/Latino, 18 White/Caucasian, 1 Black/African-American, 37 other) consisted of 47 control and 48 gratitude dyads.

Design. Each dyad was randomly assigned to the control or gratitude condition. Within each condition, one participant was randomly assigned to be the *expresser*, who would express gratitude or a control expression to the receiver; the other participant was randomly assigned to be the *receiver*, who would listen to the expresser and respond as they would in a normal conversation.

Procedure (see Figure 1.1 for an overview). In separate testing rooms, two participants completed intake questionnaires and had physiological sensors attached. After acclimating to the lab for 5 minutes, baseline physiological recordings were collected for 5 minutes while participants were seated and resting alone in the room. Next, participants completed self-report measures on a tablet computer and selected the topic they might discuss during the initial conversation and completed the brainstorm portion of the experimental manipulation (see Supplemental Material). Members of the dyad were then brought together in a large testing room and completed the gratitude or control expression task (see details in "*Experimental manipulation*" section). Finally, all participants completed the collaborative work task followed by the individual performance task, during which we assessed challenge- and threat-patterned physiological responses.

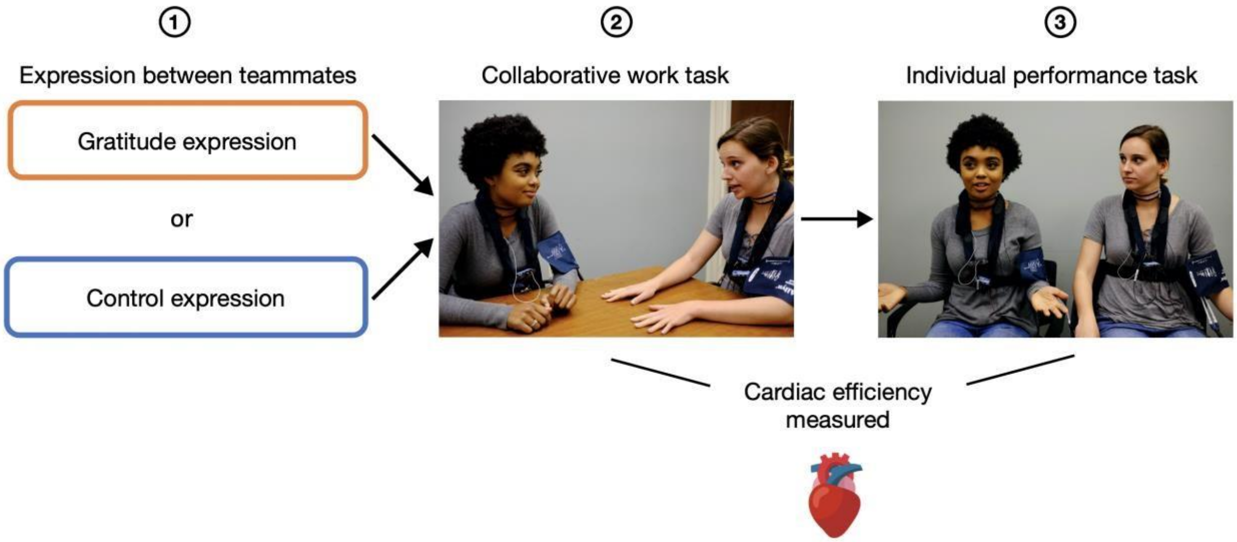

Figure 1.1. Procedure overview. 1) Dyads first completed a gratitude or control expression task. 2) The teammates next completed the *collaborative work task* during which they designed a product, marketing plan, and pitch. 3) Each teammate then completed the *individual performance task* by presenting their part of the product pitch to evaluators.

Experimental manipulation. When completing questionnaires alone, all participants were asked to generate a topic they might discuss in an upcoming conversation. In the *gratitude* condition, the expresser selected the topic they might discuss with their teammate by writing about an action by their partner (the other participant) for which they felt grateful (Algoe, Fredrickson, & Gable, 2013). The expresser wrote down what their partner did to cause them to feel gratitude, and why the behavior was especially great and praiseworthy. All other participants (i.e., the receiver in the gratitude condition and both participants in the *control* condition) wrote about ordinary aspects of an average day (e.g., what their course schedule was like, what they did between classes).

When members of the dyad reunited, the experimenter revealed the roles to the participants. The expresser then discussed the events they wrote about, either gratitude or control depending on the condition, while both participants were seated at a table for a maximum of two minutes. During this time, the receiver listened and responded naturally, engaging in the topic as much or as little as they would in a normal conversation. Immediately after the conversation, the expresser and the receiver were asked to assess how grateful they felt and their partner appeared during the conversation on a 1 (*not at all*) to 5 (*very much*) scale, along with a variety of other emotions (see Supplemental Material).

Collaborative work task and individual performance task. Challenge- and threat patterned physiological responses were assessed during a collaborative work task (6 minutes) and then during an individual performance task (3 minutes per participant; see Oveis et al., 2020 for procedural details). Both tasks were designed to produce acute stress, and the individual performance task bears resemblance to the Trier Social Stress Task (Kirschbaum et al., 1993). During the collaborative task, the teammates together designed a bicycle, a marketing plan, and a product pitch while seated together at a table. During the individual task, the teammates took turns delivering their individual parts of their product pitch to a pair of evaluators who withheld verbal and nonverbal feedback. To ensure that participants would work together during the collaborative task, the teammates did not learn which teammate had been randomly assigned to complete part one versus part two of the individual task until after the collaborative task had concluded. To incentivize task engagement and heighten acute stress, participants were informed that the best team would receive $200.

Physiological measures. During baseline, collaborative work, and individual work, we collected electrocardiography (ECG) with a Lead II configuration, Impedance cardiography (ICG) with band electrode tapes, and blood pressure. ECG and ICG signals were sampled at 1 KHz and integrated with a MP150 (Biopac System Inc., Goleta, CA). Blood pressure readings were obtained using a Colin BP-8800 (Colin Medical Instruments, San Antonio, TX) from the branchial artery on the non-dominant arm. ECG and ICG signals were processed into 30-second segments and ensembled into segment average using Mindware software (IMP v. 3.1.16; Mindware Technologies, Gahanna, OH).

Following Oveis et al. (2020), reactivity scores were created by subtracting baseline scores from scores during the first (most reactive) minute of the collaborative and individual tasks. Analyses focused on the following measures: cardiac output (CO), total peripheral resistance (TPR), pre-ejection period (PEP), and a challenge-threat index (calculated by subtracting the z-scores of TPR from CO). PEP is a measure of sympathetic arousal. CO and TPR are measures of cardiac efficiency. CO is the amount of blood ejected from the heart per minute; higher CO is observed during challenge states. TPR is a measure of vascular resistance and is calculated as mean arterial pressure / CO * 80; a decrease in TPR indicates less resistance to blood flow to the periphery. Consistent with previous work (Blascovich et al., 2004; Seery et al., 2010), we focused on the index of CO and TPR (challenge-threat index) to maximize the reliability of the two cardiac efficiency indices; greater values on the challenge-threat index reflect greater cardiac efficiency.

Experienced/Expressed gratitude. Participants rated how "grateful/appreciative/thankful" they and their teammate felt during the conversation on 1 (*not at all*) to 5 (*very much*) scale.

Measures of performance outcome. For each of the 6 consecutive 30-second segments of the individual performance task (one 3 minute pitch for each participant, two pitches per dyad), 4 trained coders (blind to hypotheses and experimental condition) rated the extent to which each presenter performed on two 0 to 6 scales: content (the qualities of the ideas pitched) and presentation style (i.e., nonverbal aspects of the performance). Raters also provided an overall performance score on the same 0 to 6 scale for the entire pitch. Coders had access to both audio and video for all codes. Coders' content rating only account for verbal content, and their performance only account for nonverbal aspects of the presentation. The overall rating accounted for any verbal and/or nonverbal channels (including face, voice, gaze, gesture, posture, and verbal content). The 4 trained coders overlapped on 20% of the corpus of video recordings (40 videos), and showed excellent inter-rater reliability in their ratings (alphas: content (.92), presentation (.93), and overall score (.91)). Average of content and presentation, as well as the overall score, across the individual presentations were retained for analysis.

1.3 Results

Manipulation check. The gratitude condition successfully produced gratitude in the expresser, as felt by the expresser and perceived by the receiver. Expressers in the gratitude condition ($M = 4.54$, $SD = 0.62$) felt significantly more grateful during the conversation than expressers in the control condition ($M = 3.38$, $SD = 1.14$, $F(1,93) = 38.79$, $p < .001$, 95% CI [0.73, 1.41], $d = 1.28$). Receivers in the gratitude condition rated their expresser counterparts as experiencing more gratitude ($M = 4.47$, $SD = 0.75$) than receivers in the control condition ($M = 3.31$, $SD = 0.90$, $F(1,93) = 46.07$, $p < .001$, 95% CI [0.81, 1.48], $d = 1.41$).

Do teammates show more challenge-type stress responses after a gratitude expression? Our focal analyses examined whether team members showed more efficient stress responses following a gratitude expression from one teammate to another. To examine potential data non-independence within dyad, we built a two-level multilevel model nesting participant within dyad using the nlme package (v3.1-141, Pinheiro et al., 2019) in R (R core team, 2019). Significant dyad-level variance was observed for PEP (χ^2 (1) = 5.90, p = .015). Although dyadic variance was not significant for challenge-threat index ((χ^2 (1) = 0.71, p = .399), the 95% confidence interval showed a non-zero random effect estimation [0.09, 0.98]. And we account for the non-independence in all models to keep them consistent between DVs and to best represent the structure of the experimental design. Therefore, to account for this interdependence in the data, we conducted all analyses using two-level nested models of participant within dyad.

Baseline. No baseline physiological differences were observed between the two conditions (PEP: F(1,92) = 0.43, p = .512; CO: F(1,92) = 0.70, p = .403; TPR: F(1,92) = 0.60, p = .439).

Collaborative work task: PEP. As intended, the collaborative task elicited sympathetic arousal and was demanding: Collapsing across conditions, participants showed a significant decrease in PEP during the collaborative task compared to baseline (M = -8.82, SD = 11.94; t(174) = -9.77, p < .001, 95% CI [-10.60, -7.04], d = -1.48). As expected, PEP reactivity did not differ between the gratitude (M = -9.51, SD = 11.91) and control conditions (M = -8.14, SD = 11.99), F(1,85) = 0.57, p = .452.

Collaborative work task: Challenge-threat index. Collapsing across conditions, participants showed significantly more threat-patterned physiological responses during the collaborative work task compared to baseline, $t(174) = -9.96$, $p < .001$, 95% CI [-0.93, -0.62].

We tested our focal hypotheses by examining how the gratitude expression manipulation impacted the challenge-threat index, which measured cardiac efficiency during stressful work. We built a mixed effect model to test the fixed effect of condition on challenge-threat index, with a random intercept for dyads. As predicted, gratitude expressions ($M = -0.59$, $SD = 1.13$) produced more challenge-patterned physiological responses compared to the control condition ($M = -0.96$, $SD = 0.88$), as measured by challenge-threat index reactivity, $F(1,88) = 5.40$, $p = .022$, 95% CI [0.83, 1.12], $d = .36$ (see Figure 1.2).

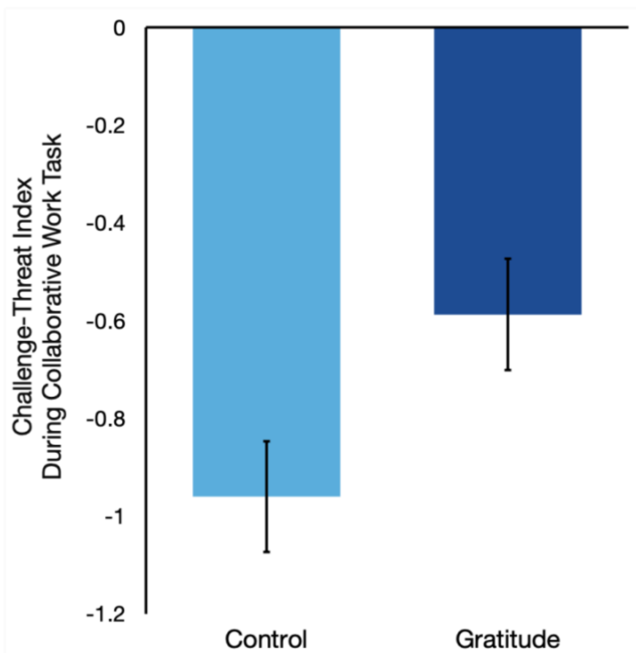

Figure 1.2. When one member of a team expressed gratitude to the other prior to engaging in stressful collaborative work, the team members showed a more efficient (challenge-patterned) cardiovascular response than controls. Error bars represent one standard error.

Individual performance task: PEP. As intended, the individual task elicited sympathetic arousal and was demanding: Collapsing across conditions, participants showed a significant decrease in PEP during the individual task compared to baseline (M = -22.11, SD = 16.64; $t(171)$ = -17.42, $p < .001$, 95% CI [-24.62, -19.61]). As expected, PEP reactivity did not differ between the gratitude (M = -22.84, SD = 18.75) and control conditions (M = -21.39, SD = 14.31, $F(1,87)$ = 0.32, p = .570.

***Individual performance task: Challenge-threat index*.** Collapsing across conditions, participants did not show significantly different challenge-threat index values between baseline and individual performance tasks, $t(155)$ = 1.59, p = .114.

We used a mixed effect model to test the fixed effect of condition on challenge-threat index, with a random intercept for dyads. As predicted, in our focal test, gratitude expressions (M = 0.46, SD = 1.71) produced more challenge-patterned physiological responses compared to the control condition (M = -0.10, SD = 1.12), as measured by challenge-threat index reactivity, $F(1,85)$ = 5.73, p = .019, 95% CI [0.09, 1.02], d = .38 (see Figure 1.3).

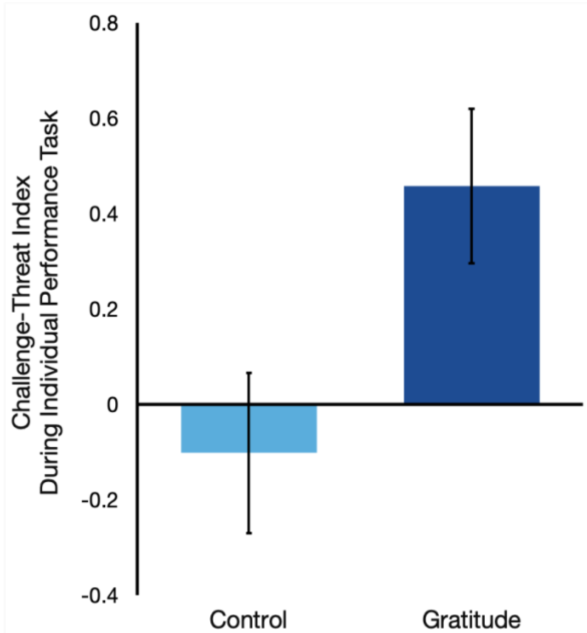

Figure 1.3. Compared to control teams, members of gratitude-expressing teams showed more efficient (challenge-patterned) cardiovascular activation during the individual performance task, which occurred temporally further from the gratitude manipulation and when teammates were no longer actively engaged with one another. Error bars represent one standard error.

Task performance

The experimental conditions did not differ significantly in individual task presentation content quality (*F*(1,92) = 0.003, p = .956), presentation performance quality (*F*(1,92) = 0.19, *p* = .663), or overall presentation quality (*F*(1,92) = 0.07, *p* = .784) (Figure 4). We found a positive correlation between cardiac efficiency during collaborative work task and content quality (*b* = 0.18, 95% CI [0.03,0.33], *F*(1,167.9) = 5.65, *p* = .017), presentation performance quality (*b* = 0.23, 95% CI [0.08,0.38], *F*(1,166.6) = 9.53, *p* = .002) and overall performance (*b* = 0.21, 95% CI [0.06, 0.36], *F*(1,168) = 7.51, *p* = .006). In addition, we also found a positive correlation between cardiac efficiency during individual performance task and content quality (*b* = 0.17, 95% CI [0.01,0.32], *F*(1,150.3) = 4.32, *p* = .038), nonverbal aspect of performance (*b* = 0.22, 95% CI [0.06,0.37], *F*(1,147.8) = 7.78, *p* = .005) and overall performance (*b* = 0.19, 95% CI

[0.03, 0.34], *F*(1,151) = 5.76, *p* = .016), which indicates that more efficient cardiac efficiency result in better performance down in the line.

However, condition didn't moderate the correlations that we found between cardiac efficiency during collaborative work task and content (*F*(1,165.29) = 0.16, *p* = .685), between efficiency and presentation (*F*(1,161.18) = 0.0003, *p* = .985), and between efficiency and overall performance (*F*(1,166) = 0.17, *p* = .677). Condition also didn't moderate the correlations that we found between cardiac efficiency and content (*F*(1,133.15) = 0.36, *p* = .550), between efficiency and presentation (*F*(1,128.29) = 1.43, *p* = .233), and efficiency and overall performance (*F*(1,149) = 1.48, *p* = .226).

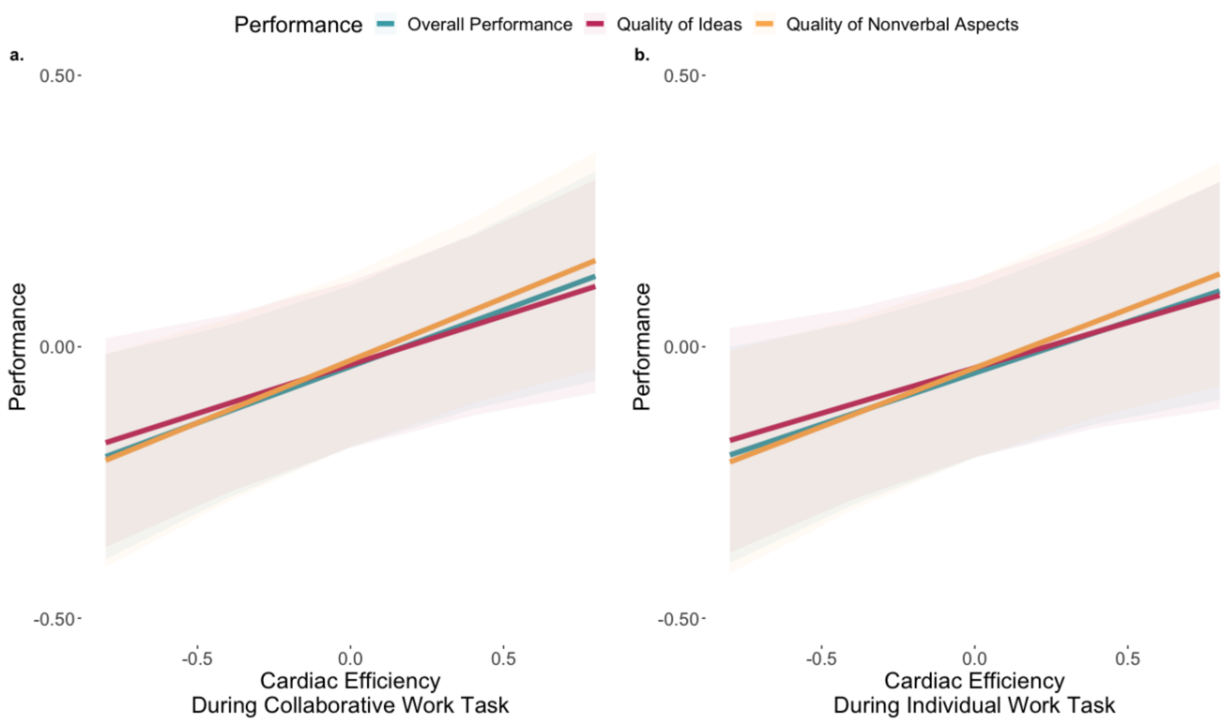

Figure 1.4. There is a positive correlation between cardiac efficiency during collaborative work task and quality of content, quality of nonverbal aspects of the pitch, and overall performance evaluation (Panel a). There is also a positive correlation between cardiac efficiency during individual performance task and quality of content, quality of nonverbal aspects of pitch ideas, and overall performance (Panel b). None of these were moderated by the condition each dyad was in.

1.4 Discussion

Building on evidence showing that gratitude builds social and psychological resources in members of romantic relationships (Algoe & Zhaoyang, 2016), we anticipated that gratitude expressions would increase *teammates'* perceptions of resources when faced with stressful tasks and elicit more challenge-patterned physiological stress responses. This pattern of results would provide the first evidence that gratitude builds biological resources, promoting better stress responses. The present study significantly advanced the gratitude literature by proposing and testing whether gratitude expressions would enhance physiological stress responding, specifically, and by demonstrating these effects in an understudied population in the gratitude literature, teammates--all in real time. Using an ecologically-valid stressful work task that increased sympathetic arousal for all participants, our hypotheses focused on cardiovascular responses that represent *efficiency* in cardiovascular responding—that is, a more *challenge patterned* physiological stress response profile. As predicted, teammates showed greater cardiac efficiency, compared to controls, when one member of the team expressed gratitude to the other in a laboratory-based conversation prior to engaging in demanding tasks. These effects were observed at two crucial time points: (1) when the teammates were working together *collaboratively* to develop a product pitch, and (2) when they *independently* pitched their part of the project to stoic evaluators. These findings substantially contribute to the gratitude literature, which has largely not produced evidence regarding physiology, nor about loose-tie social relationships (e.g., acquaintances or co-workers), which represent an important aspect of life. This work also adds an important theoretical and empirical twist in the consideration of relationship partners as *resources* during physiologically taxing episodes.

1.4.1 Physiological consequences of expressed gratitude

Several studies document psychosocial consequences of expressed gratitude for the person who expresses it and for the person toward whom it is directed: Gratitude expressions are an inherently dyadic experience. Because the central benefit of these interactions relates to improved relationship quality (Algoe, 2012), and interpersonal relationships serve as resources to help people get through stressful times (Beckes & Coan, 2011; Coan, Schaefer, & Davidson, 2006; Cohen & Wills, 1985; Conner et al., 2012; Page-Gould et al., 2014), we reasoned that an expression of gratitude would facilitate physiological resilience—in the form of more challenge-patterned physiological responses—during a stressful task. These findings are the first of which we are aware to document physiological consequences from interpersonal gratitude. Critically, this particular cardiovascular response represents a meaningful consequence with potential translation to the challenges people face in their everyday lives.

The first finding—that gratitude promoted cardiac efficiency during *collaborative* teamwork—is important because this context models acutely stressful collaborative work typical of loose-tie teams within organizations. These findings represent the first evidence of gratitude's impact on *biological* stress—research thus far has shown that dispositional gratitude is related to subjective stress (Deutsch, 1984; Krause, 2006) and helps decrease subjective stress over time (Wood et al., 2008)—as well as the first evidence of gratitude's impact on stress processes in members of dyads or teams. The second finding—that gratitude promoted cardiac efficiency further downstream, when individuals completed an *individual* performance task—is distinctly important for three reasons. First, the two teammates did not directly interact during the individual performance task; thus, direct interaction between participants was not necessary for gratitude's positive impact on biological stress responding to persist. Second, the individual performance task occurred approximately 12 minutes after the conclusion of the gratitude manipulation (in contrast to the collaborative work task, which occurred directly afterward); thus, the effect of the manipulation was durable. Third, the individual performance task was modeled on the Trier Social Stress Task (Kirschbaum et al., 1993) allowing a direct comparison to how other studies' manipulations' impact stress responding for individuals in the same context.

1.4.2 Biopsychosocial model of challenge and threat

The present research was grounded in the BPS model of challenge and threat, which sheds light on the biological mechanisms underlying how people respond to stress (Blascovich & Mendes, 2010). Gratitude expressions improved cardiovascular efficiency in the expresser-receiver dyad—facilitating delivery of oxygenated blood to the periphery and brain—in two distinct contexts: when collaborating, and later when working individually. In addition, demonstrating the physiological benefits of a simple gratitude expression in a team performance task has potentially broader implications because, relative to threat responses, challenge response is correlated with reduced attention to negative cues (Jamieson et al., 2012), facilitating decision making (Kassam et al., 2009), slower "brain aging" (Jefferson et al., 2010), and predicting academic success (Seery et al., 2010). The current study is the first to directly investigate the immediate and subsequent consequences of gratitude expression on acute stress in a dyadic team performance context.

The present work also informs challenge and threat theory by demonstrating that not only can emotion regulatory activities modulate challenge and threat responses in team performance contexts (Oveis et al., 2020), but also that emotion *expressions* (specifically, gratitude) and interpersonal dynamics can facilitate stress responses in the body. This has important implications in that it suggests potential interventions that can change the perception of one's resources versus contextual demands, thus increasing challenge states and potentially boosting task performance.

In addition, the present work also found that challenge and threat responses in teammates are associated with performance outcome, such as verbal and nonverbal aspects of individual performance task. Although performance is not different between gratitude and control dyads, these findings are consistent with previous literature on emotion regulation, demonstrating that experiencing more efficient cardiovascular responses also exhibited better performance in athletes (see Hase et al., 2018 for a review). In addition, challenge and threat states can lead to divergent behaviors or movements (O'Connor et al., 2010; Weisbuch, Seery, Ambaby & Blascovich, 2009; Mendes et al., 2007). The findings in the current study that challenge-threat response is positively related to coded performance can be explained by previous findings that a challenge state might result in superior performance by encouraging task-related movement patterns (Moore, Vine, Wilson, & Freeman, 2012). Therefore, the current study provides new evidence for future studies to explore the relationship between challenge and threat response and team performance beyond sports setting.

1.4.3 Gratitude among loose social ties

Whereas important work has been conducted on gratitude between strangers and romantic partners, a novel area of interest relates to gratitude in the workplace (Fehr, Fulmer & Miller, 2017). Adults often spend the majority of the waking day at work, engaging in social interactions within networks of looser social ties. However, few studies have examined gratitude in this important relational context (e.g., Lee et al., 2019), and none look closely at the dyad or the consequences of gratitude *in vivo*. Despite the documented benefits of expressing gratitude on strengthening social bonds (Algoe et al., 2020), many people are reluctant to express gratitude because they fear that others will not appreciate their expressions (Kumar & Epley, 2018), or perhaps fearing a loss of status in others' eyes (Chaudhry & Loewenstein, 2019). This reluctance may be exacerbated in professional settings, and research demonstrating the impact of gratitude in loose-tie teams provides an empirical basis for expressing more gratitude in the workplace. The present research presents an important methodological tool for use in future gratitude research, by presenting an ecologically valid paradigm to study gratitude's impact on teamwork and stress responding, and by focusing on resilient physiological profiles of challenge vs. threat responses.

1.5 Limitations

The following limitations should be considered in interpreting the present findings. First, even though the teammates in the present study are newly acquainted suitemates living in the same dorm, these relationships are not strictly representative of work teammates. The present research, however, suggests that work with professional teammates would be fruitful. Second, the present study employed an experimental manipulation of gratitude expressions; future work should examine individual differences in gratitude, and determine if adding a person to a team who tends to express gratitude would produce team-level benefits. Third, with the rise of virtual teamwork, we note that the gratitude expression and positive impact of stress-responding in teams occurred in a face-to-face setting. We speculate that gratitude expressions would exert similar effects when expressed via a technological medium, but future research is necessary to support this claim.

1.6 Conclusion

The present findings provide the first evidence that gratitude expressions impact biological responses in teammates, for the better. This work fits with a burgeoning literature on the social consequences of gratitude (e.g., Algoe et al., 2020), and more generally with work suggesting a myriad of positive intra- and interpersonal consequences of positive interpersonal processes (Algoe, 2019). The evidence here suggests a potential benefit of injecting gratitude into teams and organizations: One person's gratitude can positively impact a team at a biological level and promote more adaptive responses to stress.

Chapter 1, in part, is currently being prepared for submission for publication. Gu, Y.; Oveis, C. The dissertation author was the primary author of this chapter.

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Chapter 2

Suppressing emotions during collaborative work disrupts physiological linkage between teammates

2.1 Introduction

2.1.1 Overview

Teamwork is ubiquitous and an important part of life. From group projects in educational settings to cross-functional projects in organizations to coordinated responsibilities between members of a household, humans accomplish a wide variety of tasks in collaboration with others across many settings. A defining feature of teams is interdependence (Dietz et al., 2017): Successful teamwork requires active and effective coordination. Understanding the factors that facilitate or diminish team coordination is imperative, but interpersonal coordination and cohesion processes are at present poorly understood, and measuring these processes between people during teamwork has proven to be a complex challenge (Espinosa, Lurch, & Kraut, 2004). Indeed, team coordination is often measured through subjective self-reports after-the-fact, or is measured by the quality of the final product rather than the process that produced it ***(***see review in Okhuysen & Bechky, 2009***)***. In this paper, we suggest that respiratory sinus arrhythmia (RSA) linkage, a biological index of co-regulation between people, can provide important, online information about the *process* of coordination between teammates.

Recent advances in affective science have enabled an understanding of how members of dyads coordinate with one another during social interactions (e.g., Butler & Randall, 2013). This process of *co-regulation* can be captured continuously and unobtrusively with RSA linkage, a measure that assesses the degree to which parasympathetic nervous system-mediated patterns of heart rate variability are entrained between two people (Helm, Sbarra, & Ferrer, 2014). Previous literature has also explored that bodily synchronized with one another may be a fundamental way for instantiating a socioemotional connection with another and associated with more coordination and cooperation (Marsh, Richardson, & Schmidt, 2009). Investigating whether RSA linkage occurs during teamwork is important because it offers theoretical contributions about *how* people implicitly coordinate with one another to accomplish tasks, and a methodological contribution of a new method for assessing effective teamwork. The present paper not only seeks to determine if RSA linkage emerges between teammates, but also tests whether emotion dynamics in teams—specifically, how teammates attempt to *regulate* their emotions—impact team coordination, as assessed via RSA linkage. We focus on whether a single teammate's *suppression* of their emotions—a common emotion regulation strategy deployed during high stakes teamwork—impairs the physiological bond between the pair. We thus used an ecologically valid, dyadic experimental paradigm in which teammates engaged in a collaborative task and an individual performance task to answer two major questions: (1) Does RSA linkage emerge between team members during teamwork? And (2) does suppressing emotion expressions disrupt this physiological coordination between teammates.

2.1.2 Emotion regulation

Emotion regulation, efforts to change one's emotional experiences or expressions (Gross, 1998), is widely studied. Emotion regulation impacts a vast array of important consequences, including health decisions (DeSteno, Gross, & Kubzansky, 2013; Ford, Karnilowicz & Mauss, 2017), relationships (English, John, & Gross, 2013), and academic work performance (John & Gross, 2004; Jamieson et al., 2010). Two emotion regulation strategies—cognitive reappraisal and expressive suppression—have received extensive attention in empirical work (Gross, 2002, 2015). Whereas reappraisal involves reframing or rethinking an emotion-eliciting situation so that it no longer elicits the same emotional response, suppression is the act of hiding, restricting, or decreasing emotion-expressive behavior while experiencing emotional arousal (Gross, 2002; Gross & John, 2003). The majority of research on reappraisal and suppression has examined the *intra*personal correlates and consequences of these strategies. Here, we aim to understand an interpersonal emotion regulation effect that is particularly relevant to teams: the incidental social effects of emotion regulation. That is, when one teammate attempts to change their own emotions, how might that impact their social coordination and cohesion with teammates.

In this paper, we focus on suppression for two reasons. First, the use of expressive suppression is prevalent in everyday life (English & John, 2013), enhancing the external validity of the study of emotion suppression in teams. Second, a growing body of empirical evidence suggests that suppression compromises social functioning, such as in parent-child relationships (e.g., Karnilowicz, Waters, & Mendes, 2018), romantic relationships (e.g., Butler et al., 2006; Peters & Jamieson, 2016), and workplace interactions (Grandey, 2000). While a lack of emotion expression can be helpful in some contexts (e.g., withholding emotion expression can be helpful for judges and therapists when facing clients (Grandey, 2000)), it has been experimentally demonstrated to result in reduced rapport between romantic couples (Impett et al., 2013), inhibited relationship formation, disruption in communication between individuals, and increased blood pressure during social interaction (Butler et al., 2003). Chronic emotion suppression has been linked to higher rates of depression, anxiety, and stress-related symptoms following traumatic events (Amstadter, 2008; Joormann & Gotlib, 2010; Meyer, Smeets, Giesbrecht, & Merckelbach, 2012; Moore, Zoellner, & Mollenholt, 2008). However, while experimental studies of suppression have focused romantic or stranger pairs, little is known about suppression in teamwork settings. And no studies in any relationship context have examined whether suppression impacts physiological linkage between people.

Here, we test whether suppressing one's emotions in a team setting might break the physiological bond between teammates, noting a second defining feature of teamwork: Teamwork is often stressful. Teammates work together under tight deadlines, difficult coordination requirements, and evaluation pressures (Dietz et al., 2017). Because of this, teammates often take actions to regulate their *own* stress while engaged in teamwork with others. To the extent that one teammate's intrapersonal regulatory actions change the emotion expressive cues present during teamwork—as does suppression—it stands to reason that the linkage between teammates would be impacted. However, this question has yet to be tested; answering this question would critically contribute to the emotion regulation literature's understanding of the social consequences of intrapersonal emotion regulation.

Moreover, human are social beings, and we spend a lot of our waking time around other people. Despite evidence demonstrating that 90% of intrapersonal emotion regulation occurs in social contexts, research on emotion regulation has largely centered on intrapersonal correlates and consequences (Campos, Campos, & Barrett, 1989; Gross, 1998, 2015; Gross, Richards, & John, 2006; Lopes, Salovey, Côté, Beers, & Petty, 2005; Richards & Gross, 2000). Thus, understanding the interpersonal consequences of emotion regulation is critical. However, the nascent study of interpersonal emotion regulation has thus far focused on efforts to change others' emotions (Zaki & Williams, 2013) or efforts to regulate one's own emotions via social interaction (Williams, Morelli, Ong & Zaki, 2018). Very few studies in the literature have examined the contagion effect intrapersonal emotion regulation, but none provided direct evidence of how suppression, specifically, impact teammates. One study on contagion effect of teammate's intrapersonal emotion regulation found one person' reappraisal positively impacted a social partner's stress response (Oveis et al., 2020). Another study examining emotion regulation in parent-child dyads found mothers suppressing their emotions influenced their child's *sympathetic response* (Waters et al., 2020). However, none of these studies provide evidence on whether physiological linkage emerges between teammates during teamwork, or the impact of emotion regulation on physiological linkage between teammates. These questions are the focus of the present study.

2.1.3 RSA

To facilitate rapid responding to threats and social opportunities, the parasympathetic nervous system (PNS) exerts rapid control over the heart rate via the vagus nerve, which in parallel aids in the regulation of communication-relevant organs such as the eyes, ears, and vocal cords (Porges, 2001). PNS (vagal) activity can be captured in a measure of heart rate variability known as respiratory sinus arrhythmia (RSA), which reflects the fact that increased PNS activity causes greater differences between heart rate during inhalation and exhalation. In comparison to the sympathetic nervous system, the PNS is relatively fast and more flexible for influencing cardiac arousal (order of milliseconds vs. order of seconds; Thayer & Lane, 2000). Consistent with theoretical perspectives on the PNS's role in the regulation of social interaction, higher RSA is related to tendencies toward social connection and engagement with others, the experience of positive emotions, other-oriented social engagement, aspects of social well-being, and predicts less disengagement strategies to regulate negative emotions (Butler et al., 2006; Porges, 2007; Stellar et al., 2015, Oveis et al., 2009; Porges et al., 1996; Wang, Lu & Qin, 2013, Geisler, Kubiak, Siewert, & Weber, 2013; van Kleef et al., 2008). These findings reflect that RSA holds promise in capturing positive processes of social engagement between people. In the present paper, we investigate how RSA *linkage*—the observation of coordinated changes in RSA between people who are engaged with one another—may hold promise in capturing mutual engagement between teammates.

Physiological linkage is theorized to be an interpersonal process whereby physiological activation in an individual is coordinated with or influences physiological activation in another individual (Butler, 2011; Timmons et al., 2015). Recent studies indicate that children's emotions can be impacted by their parents' emotional states and regulatory efforts via synchronization of sympathetic physiological responses (Waters et al., 2020; Waters, West, Karnilowicz, & Mendes, 2017; Waters, West, & Mendes, 2014). These studies, which focus on parent-child relationships, focus on sympathetic physiological linkage. In contrast to *sympathetic* nervous system linkage, which assesses how people react to or "catch" the stress arousal and negative emotions of their interaction partners, RSA linkage holds particular promise for assessing positive engagement and coordination processes between people due to RSA's theoretical and empirical links with positive emotion, social engagement, and social coordination (Porges, et al., 1996; Stellar, Cohen, Oveis & Keltner, 2015; Di Bello et al., 2020). In parent-child dyads, RSA linkage is present between mother and preschoolers during interaction tasks (Lunkenheimer et al., 2015, 2017). In romantic couples, RSA linkage emerges when one discloses success to their partner (Gable, Reis, Impett, & Asher, 2004) and is associated with couples' relationship functioning and satisfaction (for a review, see Han, Baucom, Timmons, & Margolin, 2021). Greater RSA linkage is associated with higher relationship satisfaction, perhaps because RSA linkage indicates coregulation and deploy physiological resources as needed (Thayer & Lane, 2000; Helm, Sbarra, & Ferrer, 2014). Thus far, however, research on dyadic co-regulation has largely focused on romantic partner dyads (Butler & Randall, 2013; Helm et al., 2014; Reed, Barnard, & Butler, 2015; see review by Timmons, Margolin, & Saxbe, 2015). Because of the potential of RSA linkage to capture positive engagement, coordination, and mutual influence between two people, it holds promise as an online and continuous measure of team engagement; however, no research has examined or determined whether RSA linkage occurs between teammates.

Building on these findings from romantic couples, we expect to observe significant RSA linkage between teammates who are effectively engaged in teamwork. But because suppressing emotions can interfere with one's engagement in social relationships, diminish the presence of emotion signals that coordination relies upon, and disrupt the dynamics between dyad members (Butler et al., 2003; Srivastava et al., 2009), we hypothesize that suppressing emotions during teamwork would disrupt team coordination, which should be observable in diminished RSA linkage between teammates. RSA synchrony emerges because of adaptive interaction patterns of two people responding to each others' emotions. Emotion suppression may exert two types of negative effects on a dyad, each reducing the likelihood of RSA synchrony emerging. First, emotion suppression should reduce the presence of emotion expressive signals, making it more difficult for a suppressors' partner to recognize what the suppressor is feeling. Second, suppression exerts cognitive load on the suppressor (Richards & Gross, 2000), and may make the suppressor's cognitive work in recognizing their teammate's emotions less likely or effective.

2.1.4 Current study

The present study, for the first time, examines (a) whether RSA linkage emerges during intensive teamwork, and (b) the impact of emotion suppression on RSA linkage during teamwork. The current study makes a few important contributions to the literature. First, it is important to understand the existence of physiological linkage in teamwork settings. Teamwork is often stressful due to pressures of time, coordination, and performance/evaluation. And given the conceptual and empirical links of RSA with social engagement and mutual stress management, it's particularly important to understand whether RSA linkage occurs during teamwork, and under what conditions. Findings along these lines will provide insights into interpersonal dynamics in team settings and the interpersonal effects of emotion regulation. Second, we will assess whether emotion regulation impacts physiological synchrony, particularly RSA synchrony, in teams. One previous study showed that one person's reappraisal can impact the cardiovascular efficiency of their partner (Oveis et al., 2020), but no study has examined how emotion regulation impacts RSA linkage between teammates. Not only does this work contribute to the understand of emotion regulation and of teamwork, the work also makes important contributions to the literature on physiological synchrony given that a majority of the existing research has been concerned with sympathetic linkage (Kraus & Mendes, 2014; Levenson & Gottman, 1983; Thorson & West, 2018; Waters, West, & Mendes, 2014), with few studies examining RSA linkage in any context (e.g., Helm et al., 2014). Our design and analyses allow us to determine whether physiological linkage occurs due to social interaction, and to rule out spurious physiological linkage that might be observed as a measurement artifact of being in a similar context. And, by using an ecologically valid paradigm involving real, stressful teamwork requiring constant communication and coordination between teammates, we enhance the external validity of the work. The current study will test the impact of different emotion regulation strategies on RSA linkage in an ecologically valid teamwork setting, providing critical evidence regarding how intrapersonal emotion regulation efforts impact the coordination of teams.

2.2 Methods

Sample size determination. Prior to data collection, we conducted *a priori* sample size determination. We planned to test several questions with the present study. Therefore, we based the sample size on the effect that requires the most participants and increased our target sample sized based on an expectation of 10% data loss, which yields to 300 participants (see more in Oveis et al., 2020). For the present study, we used *ANOVA: Repeated Measures, within-between interaction* method in G * Power to confirm sample size needed, following Danyluck & Page-

Gould (2019), with an anticipated effect size of r = 0.14 and power of 0.8. It indicated that we needed at least 72 participants in total, which has an actual power of 0.81. Therefore, we were well-powered to test this effect.

Participants. Three hundred students were recruited from the undergraduate population of the University of California, San Diego (UCSD) and the University of Rochester. Students in the study participated in same-gender, same race/ethnicity dyads for course credit. Of the 150 dyads (300 participants), 71 were run at UCSD, and 79 were run at the University of Rochester. Data was collected from both research labs using identical procedures, physiological systems, software, and standard data scoring and analysis procedures. Seventeen dyads were excluded as a result of participants' prior knowledge of each other (1) and unusable physiological data due to experimenter error (2) and issues with sensors (14), leaving a total of 133 dyads (N = 266, 60% female).

Design. Each dyad was randomly assigned to one of the three conditions: control, reappraisal and suppression. Within each dyad, each participant was randomly assigned to be either the manipulated teammate or the non-manipulated teammate. Only the manipulated teammate received the experimental manipulation (see detail in Procedure section). The non-manipulated teammate didn't receive any manipulation instruction. Depending on the condition they were randomly assigned to, the instructions directed the manipulated teammate to either suppress their emotions or reappraise their stress arousal as helpful.

***Procedure Overview* (see Figure 2.1 for an overview).** Upon arrival, participants were separated into individual rooms to complete consent forms, as well as an intake questionnaire concerning demographic and health information, and then the experimenter applied the physiological equipment to the participant. The participants were asked to rest for 5 minutes for *baseline recording.* After baseline, the manipulated teammate received *experimental manipulation*, in which they were asked to reappraise their emotions, suppress their emotions, or didn't receive any instruction. Then the two teammates were brought together to a single testing room, got introduced, and complete the 6-minute *collaborative work task*, in which they engaged in demanding, face-to-face collaborative teamwork to design a product and a pitch. Next, each participant completed a Trier-style *individual performance task*, where they presented a 3-minute product pitch to trained evaluators. (For more procedure details and other results, please see Oveis et al., 2020.)

Baseline recording. As signals from the physiological sensors were checked, each participant acclimated in their individual rooms to the laboratory setting for 5 minutes. Once all of the physiological sensors were affixed appropriately, participants were told to rest quietly while seated alone in their rooms for a 5-minute baseline recording. Afterwards, participants completed a battery of self-report measures.

Experimental manipulation. The manipulated teammate was the only participant in the dyad to receive emotion regulation instructions after baseline. These were provided on a piece of paper and also read aloud by the experimenter. In the suppression condition, the manipulated teammate heard and read the instruction that not showing and displaying their emotion may help with their performance. In the reappraisal condition, the manipulated teammate received instruction about limiting displays of emotions prevent others from judging them negatively (see detail in Appendix). And in the control condition, the manipulated teammate received no special instructions. Immediately before the individual work task, the manipulated teammate was given the manipulation instructions once more to ensure that the experimental manipulation was being kept in mind. As manipulation check, participants were asked to what extent they *tried* and *succeeded* in suppressing their emotion on a 1 (*Disagree Strongly*) to 5 (*Agree Strongly*) scale.

Figure 2.1. Procedure overview. The *manipulated teammate* received reappraisal, suppression, or control instructions (the *non-manipulated teammate* received no special instructions). The two teammates then completed the *collaborative work task* (Panel A), during which they designed a product, marketing plan, and pitch. Next, each teammate completed the *individual performance task* by presenting Part 1 (Panel B) or Part 2 (Panel C) of the product pitch to evaluators who provided neutral verbal and nonverbal feedback (Panel D). *Note*: All teams were matched on gender and race/ethnicity. From Oveis et al., 2020. Reprinted with permission.

Collaborative work task. Participants were brought together in a common room, and the manipulated and non-manipulated teammates were introduced to one another. There, they were instructed to conduct a modified Trier Social Stress Task (Kirschbaum, Pirke, & Hellhammer, 1993), during which they needed to collaborate on creating a design, marketing plan, and pitch for a bicycle. They were told that the pitch would consist of two parts, where part one would focus primarily on sharing the design and features of the product and part two would focus primarily on sharing the marketing strategy (e.g., advertising and budget) for the bicycle.

Importantly, neither participant knew which part of the pitch they would be delivering until after the collaborative work task ended so they had to prepare for both parts together; in other words, they had to constantly communicate and work as a team, rather than divide and conquer. The teammates were allotted six minutes to collaborate on the task, during which physiological measurements were taken. In addition, the teammates were informed of a $200 incentive for the best-performing team. This procedure allowed us to assess physiological synchrony during face-to-face teamwork.

Individual performance task. Each teammate was randomly assigned to present part one or part two of the product pitch to two evaluators, who were trained to refrain from displaying cues (verbal and nonverbal) indicative of positive feedback. The pitch presentations lasted for three minutes each. If participants finished before their three minutes concluded, they were told to continue speaking by the evaluators until all three minutes had been used. It was modeled after the Trier Social Stress Test (Kirschbaum, Pirke, & Hellhammer, 1993), which consistently prompts stress reactions in individuals.

Physiological Measures. Physiological sensors were applied to all participants to measure electrocardiography (ECG). Signals were collected during the baseline, collaborative work task, and individual performance task phases of the experiment. ECG data were obtained via dot electrodes placed in Lead II configuration on the shoulders and torso, and respiration rate data was obtained via a respiratory belt transducer placed on participant's torso. BioNomadix wireless ECG amplifier and MP150 (Biopac Systems, Inc., Goleta, California) were used to collect ECG signals. ECG was ensembled into 30-second averages and edited using Mindware software (HRV v3.1.5). Using Mindware HRV software, ECG waveforms were visually inspected, all R peaks were manually verified and hand corrected/scored, and RSA was calculated in the frequency of spontaneous respiration using a 0.12-0.40 Hz bandpass filter, following standard guidelines (Camm et al., 1996).

Measures of performance outcome. For each of the 6 consecutive 30-second segments of the individual performance task (one 3 minute pitch for each participant, two pitches per dyad), 4 trained coders (blind to hypotheses and experimental condition) rated the extent to which each presenter performed on two 0 to 6 scales: content (the qualities of the ideas pitched) and presentation style (i.e., nonverbal aspects of the performance). Raters also provided an overall performance score on the same 0 to 6 scale for the entire pitch. Coders had access to both audio and video for all codes. Coders' content rating only account for verbal content, and their performance only account for nonverbal aspects of the presentation. The overall rating accounted for any verbal and/or nonverbal channels (including face, voice, gaze, gesture, posture, and verbal content). The 4 trained coders overlapped on 14% of the corpus of video recordings (40 videos), and showed excellent inter-rater reliability in their ratings (alphas: content (.92), presentation (.92), and overall score (.93)). Average of content and presentation, as well as the overall score, across the individual presentations were retained for analysis.

2.3 Results

Analysis plan. RSA linkage was assessed during two phases—the collaborative work task and the individual performance task. To examine the RSA linkage, a mixed modeling approach was used (Danyluck & Page-Gould, 2019). Partner RSA reactivity was modeled as a function of the partner's lagged RSA reactivity (to control for serial dependency; i.e., values from the previous time point, such as the first 30 seconds, were used in the analysis of 30-60 second RSA reactivity), participant's RSA reactivity (i.e., changes from the baseline), manipulation condition (reappraisal, suppression, or control), and all 2-way interactions between the latter two variables (i.e., participant RSA x manipulation condition) in a 3-level multilevel model, where random intercepts were estimated for each pair and participant. A random slope for the participant's RSA reactivity with respect to partner RSA (i.e.: RSA linkage) and the partner's lagged RSA reactivity were estimated at the level of the dyad. All analyses used multilevel modeling, which was conducted in R version 3.6.0 using the nlme package (https://CRAN.R-project.org/package=nlme).

Manipulation check. Manipulated teammates in the three conditions evaluated themselves differently on the extent to which they *tried to* suppress their emotions, $F(2,124) = 6.60$, $p = .002$, and succeeded in suppressing their emotions, $F(2,124) = 8.99$, $p < .001$, during collaborative work, manipulated teammates in the suppression condition thought they not only *tried to* suppression their emotion more than those in control condition during the collaborative work task ($F(1,84) = 13.72$, $p < .001$) and those in reappraisal condition $F(1,82) = 6.21$, $p = .015$), but they also succeeded suppression their emotion more than those in control condition ($F(1,84) = 16.47$, $p < .001$) and those in reappraisal condition ($F(1,82) = 9.72$, $p = .003$).

Does physiological linkage emerge during teamwork?

During the collaborative task, there was an average, positive effect of RSA linkage across all dyads ($b = 0.07$, $SE = 0.024$, 95% CI [0.11, 0.21], $F(1,2586) = 10.56$, $p = .001$, $r = 0.064$; see Figure 2), indicating that participants shared RSA linkage during collaborative work task. Further, the RSA linkage effect was found to be reliable within pairs, as indicated by the random slopes for RSA linkage, $\boldsymbol{\sigma} = 0.023$, 95% CI [0.011, 0.032], $\boldsymbol{\chi}^2(3) = 24.96$, $p < .001$. To add confidence that the observed RSA linkage was due to social interaction, rather than due to a common stimulus in the experiment (e.g., the task demands), in our next analysis we paired participants with random partners with whom they did not interact. In this analysis, we observed no fixed effect of RSA linkage, $F(1,2504) = 0.08$, $p = .773$, adding confidence that social interaction between teammates, rather than the experimental context, was responsible for the emergence of RSA linkage between teammates.

During only the individual task, across all pairs, there was no evidence of RSA linkage ($F(1, 2850) = 0.09$, $p = .762$). Furthermore, the manipulation condition did not moderate the effect of RSA linkage ($F(2, 2804) = 1.25$, $p = .287$). Within each condition, control dyads ($t(2805) = 1.13$, $p = .258$), suppression dyads ($t(2805) = 0.49$, $p = .625$) and reappraisal dyads ($t(2805) = -1.05$, $p = .292$) all didn't have significant linkage.

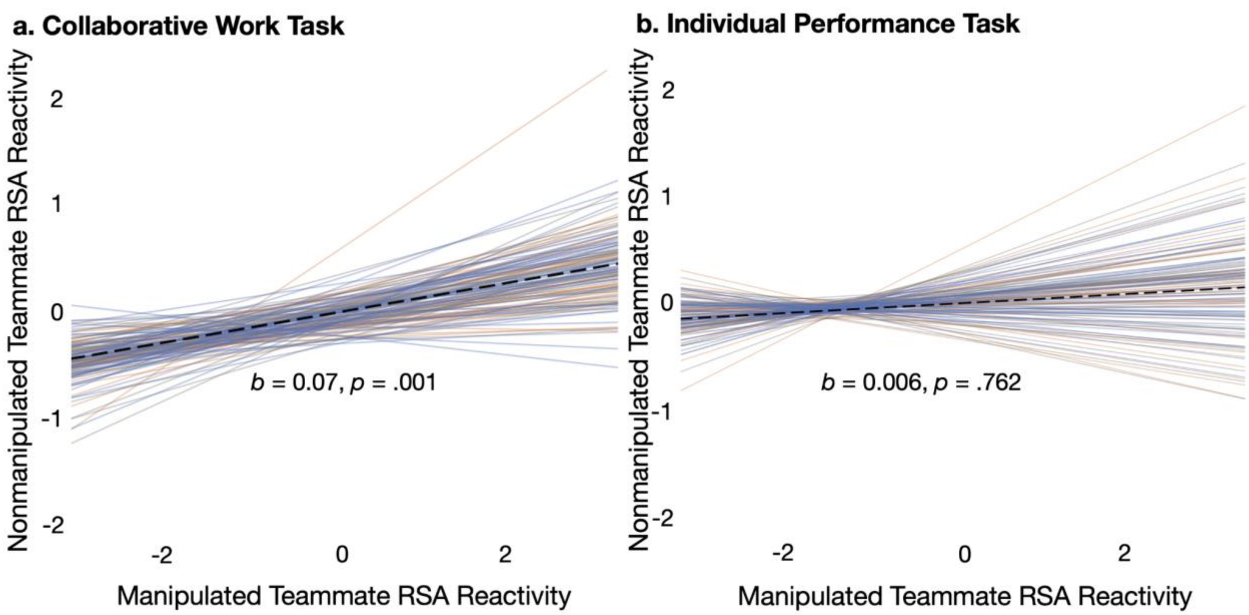


Figure 2.2. RSA linkage effects for each pair during collaborative work (Panel a) and during individual performance task (Panel b). Overall, there was significant positive RSA linkage between teammates during the collaborative work task, but RSA linkage was not observed during the individual performance task.

The emotion suppression manipulation disrupted RSA linkage during collaborative work

Examining the simple slopes (see Figure 2.3), significant RSA linkage was observed during collaborative work in the control dyads (b = 0.13, SE = 0.041, 95% CI [0.05, 0.21], $t(2545)$ = 3.17, p = .002, r = 0.06) and reappraisal dyads (b = 0.11, SE = 0.044, 95% CI [0.02, 0.19], $t(2545)$ = 2.43, p = .015, r = 0.048), but no significant RSA linkage was observed in the suppression dyads ($t(2545)$ = 0.46, p = .64). Compared to the mean of reappraisal and control dyads, suppression dyads had significantly lower RSA linkage (b = -0.03, 95% CI [-0.07, -0.001], $t(2544)$ = -0.203, p = .042). Moreover, RSA linkage was significantly lower in the suppression condition compared to the control condition ($t(1695)$ = -1.96, p = .0497), but was not significantly lower than the reappraisal condition ($t(1684)$ = 1.55, p = .123).

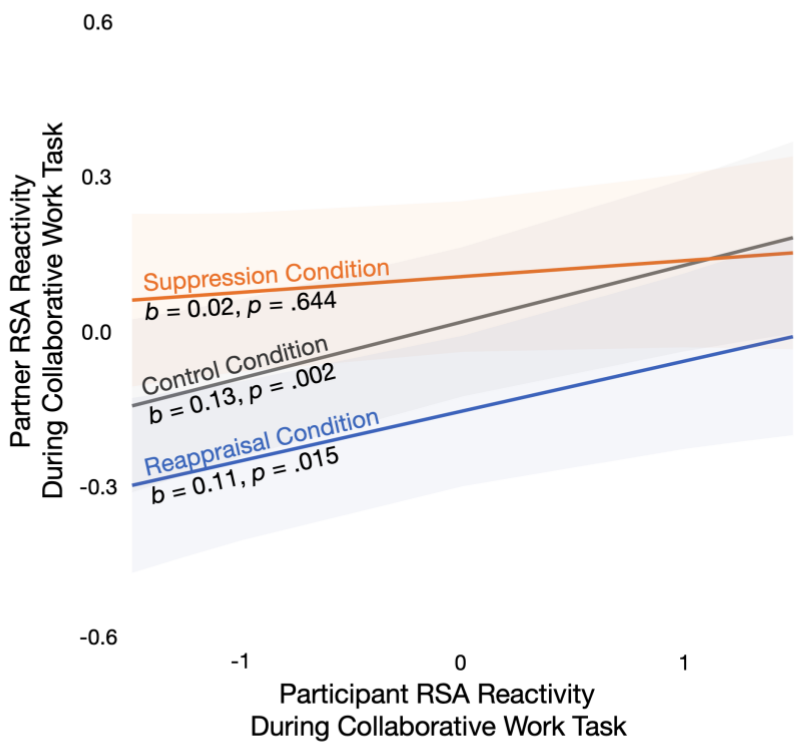
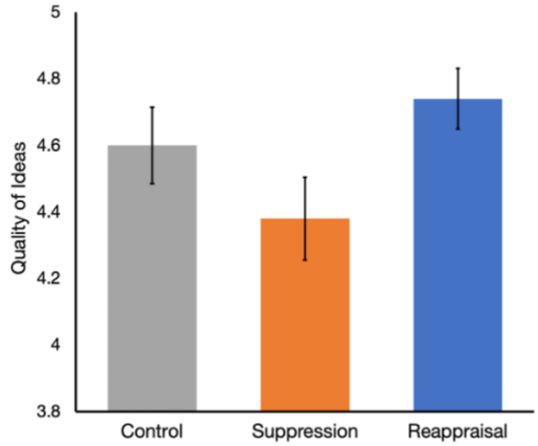


Figure 2.3. Effect of experimental manipulation on RSA reactivity during collaborative work. Whereas significant physiological linkage was observed in the control and reappraisal dyads, no significant physiological linkage was observed in the suppression dyads.

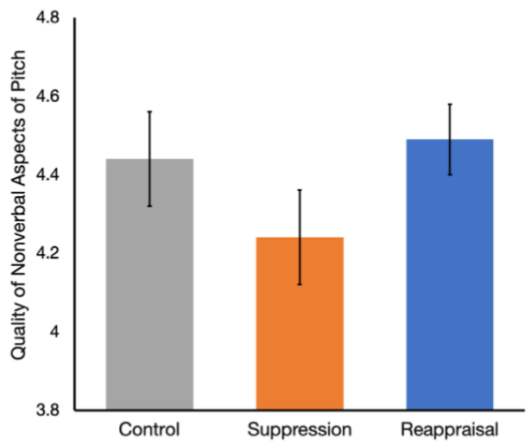
Task performance

The experimental conditions did not differ significantly in individual task presentation content quality ($F(2, 127) = 1.91$, $p = .153$), presentation performance quality ($F(2,127) = 1.16$, $p = .318$), or overall presentation quality ($F(2, 131) = 1.12$, $p = .329$) (Figure 4). In addition, RSA linkage between teammates during collaborative work was not significantly associated with presentation content quality ($F(1,123) = 0.05$, $p = .823$), presentation performance quality ($F(1, 123) = 0.019$, $p = .891$), overall presentation quality ($F(1,127) = 0.02$, $p = .870$), nor were these correlations moderated by condition (presentation content quality ($F(2,119) = 0.81$, $p = .447$); presentation performance quality ($F(2,119) = 0.60$, $p = .550$); overall presentation quality ($F(2, 123) = 0.83$, $p = .440$).

a.



b.



c.

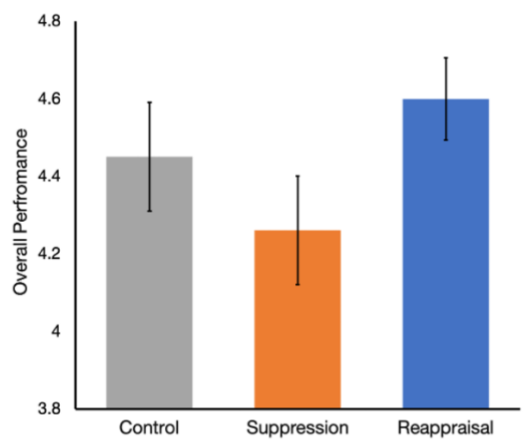


Figure 2.4. Coded performance (0-6 scale) during the individual task on quality of ideas (Panel a), quality of nonverbal aspects of the pitch (Panel b), and overall performance (Panel c) were not significantly different between conditions. Error bars represent one standard error.

2.4 Discussion

Teamwork pervades everyday life and is critical to the functioning of workplaces, education settings, and society more generally. Teammates must coordinate with one another effectively to achieve common goals and must effectively manage their emotions to optimize their performance with others. Thus, it is vital to understanding the dynamics of team coordination—*how* teammates coordinate with an regulate one another during teamwork. The present work offers two key contributions across its two aims, and does so with continuous biological assessments during real, stressful, ecologically valid teamwork. First, in demonstrating that teammates' RSA responses synchronize during teamwork, the present show that teammates co-regulate one another physiologically during teamwork. This demonstration of physiological linkage provides insight into dynamic co-regulatory processes that underly coordination and cannot easily be assessed with other measures, like post-task subjective surveys. Second, by showing that an emotion regulation strategy—expressive suppression—disrupts physiological linkage during teamwork, the present findings offer key insights on how the way that teammates deal with their own emotions impacts the quality of social interactions in the context of teamwork. While past work has observed RSA linkage between interacting romantic partners, no previous studies have investigated whether RSA linkage emerges in a different type of relationship that is important to understand—teammates—nor have any studies tested how emotion regulation strategies influence RSA linkage between people.

The present study is the first to show that RSA linkage emerges between teammates during collaborative work, and in doing so provides a key methodological advance in the study of teamwork because it will provide a relatively more objective yet dynamic measurement of coordination between teammates. This result is not only the first to show the existence of parasympathetic (RSA) synchrony between teammates, but also indicates the potential of using this new method to assess coordination between teammates. The current findings introduce a novel method for assessing coordination between teammates, and future work can investigate the short- or long-term implications for team dynamics, performance, cohesion, etc. More importantly, it also indicates how teammates coregulate under stress and during motivated tasks, which are critical for team settings.

This evidence offers important contributions to the emotional contagion and physiological linkage literatures. Previous work has shown that RSA linkage is a useful index of regulatory processes between romantic partners; RSA linkage between romantic partners is associated with health and relationship quality (Gates et al., 2015; Han et al., 2021; Helm et al., 2014; Timmons et al., 2015). While previous literature on RSA linkage focused on close relationships and parent-child relationship (see reviews: Timmons et al., 2015; Han et al., 2021), the current study expands RSA linkage finding to newly formed teams performing motivated tasks. A few studies have found physiological linkage in cooperation settings (e.g., Behrens et al., 2020; Thorson et al., 2021), but these studies are different because they studied cooperation using economic games, which are different from real-life teamwork, or focus on negotiation and influence rather than collaboration. Prior to the current study, it was not clear if a long-standing, close relationship bond is necessary for the emergence of physiological co-regulation. Our findings—that physiological linkage emerges between newly-acquainted teammates during cooperative work—thus demonstrates that a long-term bond is not necessary for physiological linkage to emerge during motivated teamwork. Given the presence of motivation to work together, teammates regulate one another from the outset of a working relationship. These findings suggest that physiological linkage is likely a feature of effective teamwork in established working relationships (such as co-workers in an organization) as well.

Because of two key analyses to rule out alternative explanations for the observation of RSA linkage between teammates, we are able to conclude that RSA linkage emerged between teammates specifically because of their interactions with one another. These analyses showed that RSA linkage only emerged when teammates were actively interacting with one another. First, we observed RSA synchrony between teammates during the collaborative work task, but did not observe RSA synchrony during the individual performance task. This indicates that simply sharing a common goal, experiencing shared stress, and engaging in team-based activities in the *presence* of a teammate does not generate RSA linkage—instead, *active engagement* between teammates is necessary for the emergence of RSA synchrony. Second, to rule out the possibility that RSA linkage was an artifact of sharing a similar stimulus—the collaborative task environment—rather than due to social engagement, we conducted permutation tests and assigned teammates to a random partner with whom they did not actually interact. In these analyses, we did not synchronize RSA responses across the timeline of the collaborative task between participants who did not interact with one another. Thus, we can conclude that RSA synchrony emerged due to meaningful, social, dyad-specific interactive engagement processes.

It is notable that the type of physiological linkage we identified during teamwork was parasympathetic (RSA) linkage, whereas previous research has largely focused on a different autonomic system with different functions: the sympathetic nervous system. Effective cooperative teamwork interactions are likely facilitated by positive social engagement between teammates. Because of theoretical and empirical links of the parasympathetic nervous system with positive emotions, other-orientation, and social engagement (Porges, et al., 1996; Stellar et al., 2015; Di Bello et al., 2020; Butler et al., 2006; van Kleef et al., 2008), we reasoned that parasympathetic (RSA) linkage was likely to emerge between teammates during collaborative work. Finding RSA linkage during teamwork thus offers empirical contributions to theories of RSA's role in social engagement (Porges, et al., 1996; Porges, 2007). And while recent advances in the study of sympathetic linkage in dyads (e.g., Waters et al., 2020) offer a glimpse into contexts in which people are likely to take on one another's stress arousal, the present findings suggest that RSA linkage should be a focal targeted outcome for better understanding contexts involving positive social engagement.

Our central experimental tests determined that one teammate's intrapersonal emotion regulation critically shapes whether physiological linkage emerges between teammates, providing the first evidence that RSA linkage is affected by emotion regulation. Whereas significant RSA synchrony was observed between control teammates and reappraisal teammates during collaborative work, significant RSA synchrony was not observed between suppression teammates. That is, when one teammate suppressed their emotions during teamwork, it significantly disrupted the physiological coordination between teammates during collaborative work. These results provide key evidence to the literature on teams, in demonstrating how emotion regulation impacts team coordination. And the findings provide an important contribution to the emotion regulation literature, as well, in demonstrating the dyadic physiological consequences of emotion suppression. While past work has shown that emotion suppression has negative social consequences such as reduced rapport, disruptions in communication between individuals, decreased relationship quality, increased stress during social interaction (Butler et al., 2003; Impett et al., 2012; English & John, 2013; Gross, 2002; Srivastava et al., 2009), and long term health threats such as depression and anxiety (Amstadter, 2008; Joormann & Gotlib, 2010; Meyer et al., 2012), there is a lack of studies looking at social consequences of intrinsic emotion regulation (English & Eldesouky, 2020). One study has shown that suppression in parents may exacerbate physiological impacts of negative emotions in children through sympathetic response synchrony (Waters et al., 2020). However, it is unclear how this may apply to adult teammates in motivated performance settings. The current study addresses this gap in the literature by providing a biological demonstration of the social consequences of suppression in non-parent-child social settings that are important in everyday life. The current study also provides further evidence that the use of suppression is associated with social costs that could disrupt positive interpersonal functioning and impact well-being (Gross & John, 2003; John & Gross, 2004). Understanding the consequences of emotion suppression and the nature of physiological synchrony has important implications for future research on organizations, where collaborative work and social dynamics are vital to organizational health.

Whereas suppression disrupted physiological linkage between teammates, reappraisal preserved physiological co-regulation between teammates. Control teams and reappraisal teams both showed significant RSA synchrony between teammates during the collaborative work task, and no significant difference was observed between the control and reappraisal RSA synchrony slopes. Teamwork is frequently stressful, and providing team members with effective strategies for regulating their own stress while preserving team coordination is important. The present results show the potential of stress regulation as one such effective emotion regulation strategy in team settings. These findings dovetail with other work showing that when one team member reappraises their stress as helpful rather than harmful, other team members benefit with improved cardiovascular efficiency during work tasks.

2.5 Limitations

A few limitations of the present work should be noted. First, it is important to note that the teammates in this study were strangers. In real life, however, members in a work group typically have previous working history together; consequently, expectations of behavior based on these prior interactions could alter the observed effects of the study. It's important to note, however, romantic partners evidence suggests that working together often will not remove the effect. Future studies, then, should explore how intrapersonal emotion regulation might impact social partners *across* contexts and relationships. In addition, interpretations of the work discussed here were also limited by the age range and the nature of the participant pool in the sample, which was restricted to undergraduate college students. As the sample consisted of relatively young adults, a direction for future work should consider how the findings of this study might differ with a sample of older adults, such as those who have already been in the workforce for several years. Examining the effects of age on interpersonal emotion regulation via intrapersonal emotion regulation could be particularly relevant for age-heterogeneous work groups, especially since previous studies regarding intrapersonal emotion regulation have found different patterns of emotion regulation strategy use between younger and older adults (Brummer, Stopa, & Bucks, 2013).

Furthermore, the present research focused on whether and when linkage emerges between teammates, but does not lend itself to drawing conclusions about interpersonal mechanism of such physiological linkage, as well as how it impacts task performance. It is possible that different behaviors and interpersonal dynamics could serve as mechanisms for how stress regulation approaches facilitate physiological linkage. For instance, while participants in the current study did not come into physical contact with each other, empirical work from the literature on physiological linkage has demonstrated that physical touch can play a critical role in and moderate the transmission of stress from mothers to infants (Waters et al., 2017). Thus, future research should investigate other potential stress regulation-facilitated physiological linkage mechanisms stemming from processes involving behaviors and interpersonal dynamics other than visual cues or subjective perceptions.

In addition, the current study did not show that RSA linkage is related to performance, nor was emotion regulation related to performance. As current study is a part of a larger scale study, the study design was to examine how emotion regulation strategies impact stress response and maximize engagement and collaboration (Oveis et al., 2020). The current paradigm was not designed to assess task performance: The modified Trier Social Stress task was designed to put teammates under extreme time and social evaluation pressure; although we behaviorally coded performance, no significant differences by condition was observed, nor was it related to RSA linkage. Future research should utilize performance-centered tasks to test whether emotion regulation influences performance via physiological linkage and coordination.

2.6 Conclusion

The current study provides the first evidence that a part the social process of collaborative work involves physiological linkage, and that this social phenomenon is affected by intrapersonal emotion regulation during stressful motivated tasks. Parasympathetic (RSA) linkage emerged only when teammates were directly engaged with one another, adding confidence that this physiological linkage was a product of social engagement processes. And, critically, when one teammate was instructed to suppress their emotions, the physiological bond between teammates was broken. Together, the current findings provide critical insight into the larger domain of human social interaction, and provide a novel approach to assessing interpersonal dynamics and the coregulation of stress that can be applied in real-world settings.

Chapter 2, in part, is currently being prepared for submission for publication. Gu, Y.; Oveis, C. The dissertation author was the primary author of this chapter.

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Conclusion

In conclusion, this dissertation presented first empirical evidence that 1) gratitude expressions impact physiological stress responses in teammates, for the better, and 2) physiological linkage not only exists during team collaboration but also plays an important role in how one person's regulation of emotions influences others. The current proposal made several important contributions. First, it fills in the gap in the literature by investigating social processes in teams that facilitates stress response and team coordination. These will have important implementation on optimizing intra- and interpersonal consequences in teamwork under stress. Second, the current proposal focuses on using an ecologically valid team stress task that is not only innovative but also provides insights of when teams work *together* and *individually*. Third, the current dissertation used physiological measures to determine consequences of social processes in teams. Critically, this dissertation reports some of the first studies to use physiological measurements, including cardiovascular efficiency and physiological linkage between teammates, to study stress response and coordination between teammates. These findings in dyads add new angles and methods of investigating biological and behavioral consequences of emotion expression and emotion regulation between teammates, which may not easily be assessed otherwise. Taken together, the current dissertation not only make contribution in affective science and psychophysiology literature, but also will bring significant advances to the broad field of social psychology, organizational behavior, and medicine.