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Gratitude Expressions Improve Teammates' Cardiovascular Stress Responses

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Gratitude expressions play a key role in strengthening relationships, suggesting gratitude might promote adaptive responses during teamwork. However, little research has examined gratitude's impact on loose tie relationships (like coworkers), and similarly little research has examined how gratitude impacts physiological stress responding or biological responses more generally. The present research uses an ecologically valid, dyadic teamwork paradigm to test how gratitude expressions impact in vivo physiological challenge and threat stress responding, assessed via a challenge–threat index composed of cardiac output and total peripheral resistance. Compared with a control condition, teammates (n = 190) who were randomly assigned to a gratitude expression manipulation showed improved biological challenge–threat responses while jointly completing an acutely stressful collaborative work task (developing a product pitch), and later while completing an individual performance task (pitching the product). During the collaborative task, gratitude expressions buffered against threat responses; during the individual task, gratitude expressions amplified challenge responses. Analyses of cardiac output (CO) and total peripheral resistance (TPR) aided in determining how cardiac outflow versus vascular constriction/dilation contributed to these effects. The finding that gratitude expressions promote adaptive biological responding at the dyadic level contributes to a growing literature on the social functions of positive emotions and gratitude, specifically. The present results also have wider implications for physiological stress in performance tasks and suggest that workplace gratitude interventions can promote adaptive stress responding in teams.

Keywords: gratitude, challenge, threat, teams

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Over the last 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 coworkers, and the potentially beneficial ways that these dynamics influence biological outcomes when members of the dyad interact. Here, we contribute substantially to 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 et al., 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 with couples in a control condition (Algoe & Zhaoyang, 2016). At the same

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The experiment reported in this article was not formally preregistered. Data and a preprint of the article are available on the Open Science Framework (https://osf.io/3rcpd/) and PsyArXiv at https://psyarxiv.com/ur5pg.

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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. In building relationships, gratitude expressions could promote more efficient team stress responses by enhancing 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). Previous research on social support also found beneficial influences of received support on physiological reactivity during stressful scenarios and links to improved physical health outcomes (Gerin et al., 1992; Krause, 2001; Lepore et al., 1993; Shaw et al., 2004).

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.

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., 2009), 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 at a biological level (Blascovich & Tomaka, 1996; Blascovich & Mendes, 2000) by focusing on two key outcomes— cardiac output (CO; the amount of oxygenated blood pumped from the heart to the periphery) and total peripheral resistance (TPR; constriction of the vasculature)—or the compensatory relationship between these two measures. Some research has suggested that CO and TPR should be assessed separately. In this approach, challenge responses are thought to involve increased CO alongside decreased TPR, whereas threat responses involve unchanged or decreased CO alongside unchanged or increased TPR (e.g., Blascovich & Tomaka, 1996; Blascovich & Mendes, 2000; Blascovich et al., 2004; Chalabaev et al., 2009; Mendes et al., 2001; Uphill et al., 2019). Whereas the present research presents individual analyses of CO and TPR for comparability with previous research in this tradition, this approach has some limitations. First, it ignores that challenge and threat responses can manifest in various ways—due to increased or reduced cardiac outflow, changes in vascular constriction/dilation, or both (Griffin & Howard, 2021, 2022). Second, and relatedly, analyzing CO and TPR separately ignores the compensatory relationship between these two variables: When one of CO or TPR changes, the other typically changes in complementary fashion to promote healthy blood flow and homeostasis; however, this is not always the case (Griffin & Howard, 2021). Third, it is desirable to have a single measurement to determine if a challenge or threat response occurred, as well as the size of the challenge or threat effect. This is particularly the case for threat responses, which, as noted, sometimes involve changes in CO and TPR, but sometimes do not. Thus, single measures incorporating both CO and TPR are useful for capturing challenge and threat responses (Griffin & Howard, 2021; Seery et al., 2010). Within the literature on the biopsychosocial model, a challenge–threat index (computed by subtracting standardized TPR from standardized CO) has played this role (e.g., Blascovich et al., 2004; Hangen et al., 2019; Seery et al., 2010). In the present article, we thus compute and focus on a challenge–threat index as our focal assessment of challenge and threat responding. Here, we offer a methodological contribution by offering a new computation of the challenge–threat index that provides a meaningful scale zero point (as we show in the online supplemental material, between-condition statistical comparisons are identical when using the typical calculation). To provide (a) comparability with related research and (b) additional information about the challenge or threat response, we additionally provide data and analyses for CO and TPR responses individually.

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 et al., 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 study 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.

The 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 improved challenge–threat 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.

Method

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 $d = .59$. Given the complexity of estimating power for multilevel analysis, we more conservatively used effect size of $d = .5$. In Optimal Design Software (Raudenbush et al., 2011), an a priori power analysis determined that 75 dyads would be necessary to achieve .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 (UCSD) participated in dyads, receiving $US24.00 each as a part of a larger study on gratitude expressions (study approved by the UCSD Human Research Protections Program under Project 151219S). Each dyad consisted of same-gender, first-year students who had been living together as suitemates for approximately four months. Ten participants were excluded due to unusable physiological data and two were excluded due to experimenter error. The final sample ($n = 190$; 144 women, 46 men; age $M = 18.1$, $SD = 1.10$, range = 18–20; 112 Asian/AsianAmerican/Pacific Islander, 20 Hispanic/Latino, 18 White/Caucasian, one 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

In separate testing rooms, two participants completed intake questionnaires and had physiological sensors attached (see Figure 1 for Procedure). After acclimating to the lab for 5 min, baseline physiological recordings were collected for 5 min 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 the online supplemental material for details). Members of the dyad were then brought together in a large testing room and completed the gratitude or control expression task (see details in the following section). Finally, all participants completed the collaborative work task followed by the individual performance task, during which we assessed challenge- and threat-relevant physiological responses.

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 et al., 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 2 min. 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 (along with a variety of other emotions) during the conversation on a scale ranging from 1 (*not at all*) to 5 (*very much*).

Collaborative Work Task and Individual Performance Task

Challenge- and threat- relevant physiological responses were assessed during a collaborative work task (6 min) and then during an individual performance task (3 min 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, electrocardiography (ECG) signals were collected using a modified lead II configuration with electrodes placed on the torso. Impedance cardiography (ICG) signals were obtained using band electrode that encircled the neck and torso. ECG and ICG signals were sampled at 1 kHz and integrated with a Biopac MP150 (Biopac System Inc., Goleta, CA), processed into 30-s segments, and ensembled into segment averages using Mindware software (IMP v. 3.1.16, Mindware Technologies, Gahanna, OH). Blood pressure readings were obtained using a Colin BP-8800 (Colin Medical Instruments, San Antonio, TX) from the brachial artery of the nondominant arm.[1] Physiological reactivity scores for the collaborative and individual tasks were computed by subtracting averaged baseline scores from averaged collaborative and individual task scores, respectively.

As indicated in the preceding text, our analyses focused on the challenge–threat index, with additional information provided from its constituent measures of CO and TPR. Pre-ejection period (PEP) was used as an indicator of sympathetic arousal during the tasks. Blood pressure data are provided in the online supplemental material. CO is a measure of the amount of blood ejected from the heart per minute. TPR is a measure of vascular resistance to blood flow to the periphery and was calculated as mean arterial pressure/CO $\times$ 80 (Blascovich et al., 2011). Challenge–threat index was calculated using a similar approach to Blascovich et al. (2004), Hangen et al. (2019), and Seery et al. (2010): They *z*-scored reactivity measures of CO and TPR, then subtracted TPR from CO. This approach advantageously creates a useful continuous index for relative comparisons between experimental conditions. However, the approach is problematic for interpreting absolute challenge- and threat-relevant responding when not comparing between conditions because the *z*-scoring renders the zero-point of the scale meaningless. Here, we offer a modification to this calculation in order to preserve a meaningful zero point on the challenge–threat index, in which values greater than zero indicate a challenge response and values less than zero indicate a threat response: In our calculation, we follow a similar procedure, but only partially standardize the scores. We divide reactivity scores for CO and TPR by their standard deviation, but do not mean-center them, using the following formula: Challenge–Threat Index = (CO Reactivity/SDCO Reactivity) – (TPR Reactivity/SDTPR Reactivity).

Using this calculation, zero indicates no particular direction for cardiovascular efficiency (i.e., no change or a mixed response), negative values reflect reduced cardiovascular efficiency, and positive values reflect greater cardiovascular efficiency. Across this dataset, our approach correlated ($r > .99$) with the typical calculation of challenge–threat index (Blascovich et al., 2004; Hangen et al., 2019; Seery et al., 2010), and produces identical results when comparing between conditions (see online supplemental material). Thus, the challenge–threat index provided a single target variable indicating whether relative differences in challenge- and threat-patterned cardiovascular responses would be observed in the gratitude versus control conditions. The CO and TPR scores, in turn, provided further information about how cardiac outflow and vascular dilation/constriction, individually, contributed to these responses.

Experienced 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.

Experienced Positive Affect

Participants rated positive emotions felt during the conversation on 1 (*not at all*) to 5 (*very much*) scales, including "amused/having fun," "love/closed/trust," "happy/pleased/joyful," "proud/good about myself," "energized/excited/enthusiastic," "admiration/inspired by others," and compassionate/sympathetic." Positive affect (PA) was retained as the average of these positive emotions ($\alpha = .84$).

Results

Manipulation Check

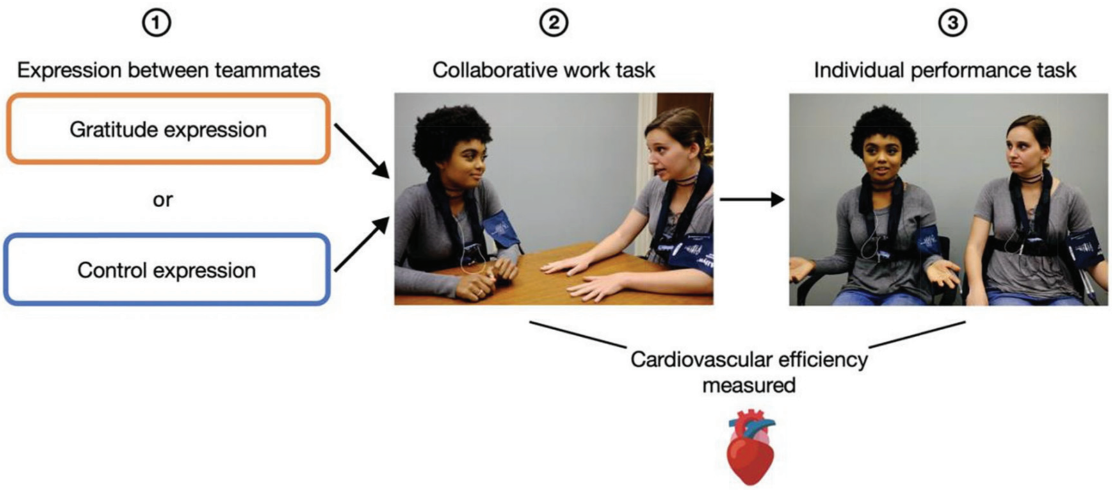
The gratitude condition successfully produced gratitude in the expresser, as felt by the expresser and perceived by the receiver. Expressers in the gratitude condition ($M = 4.52$, $SD = .62$) felt significantly more grateful during the conversation than expressers in the control condition ($M = 3.38$, $SD = 1.14$), $F(1, 93) = 37.39$, $p < .001$, 95% CI [.77, 1.52], $d = 1.26$. Receivers in the gratitude condition rated their expresser counterparts as experiencing more gratitude ($M = 4.49$, $SD = .72$) than receivers in the control condition ($M = 3.50$, $SD = .88$), $F(1, 93) = 36.18$, $p < .001$, 95% CI [.77, 1.72], $d = 1.25$.

Do Teammates Show Improved Biological Challenge–Threat 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 nonindependence within dyad, we built a two-level multilevel model nesting participant within dyad using the *nlme* package (v3.1–141; Pinheiro & Bates, 2000) in R. Significant dyad-level variance was

[1] The Colin BP-8800 was calibrated and met the performance requirements of the Association for the Advancement of Medical Instrumentation. However, we note that this blood pressure monitor failed clinical validation in a study by Naschitz et al. (2000).

Figure 1
Procedure Overview



Note. 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. Consent has been obtained from the photographed individuals. See the online article for the color version of this figure.

observed for PEP, $\chi^2(1) = 5.66$, $p = .017$. Although dyadic variance was not significant for challenge–threat index, $\chi^2(1) = 2.07$, $p = .150$, the 95% confidence interval showed a nonzero random effect estimation (95% CI [.1.31, 1.77]). We account for the nonindependence in all models to keep them consistent between dependent variables 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: $F[1, 92] = .43$, $p = .512$; CO: $F[1, 92] = .70$, $p = .403$; TPR: $F[1, 92] = .60$, $p = .439$).

Collaborative Work Task: PEP

As intended, the collaborative task elicited sympathetic arousal, indicating that the task was demanding: Collapsing across conditions, participants showed a significant decrease in PEP during the collaborative task compared with 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 ($M = –8.14$, $SD = 11.99$), $F(1, 85) = .57$, $p = .452$.

Collaborative Work Task: Challenge–Threat Index, CO, and TPR

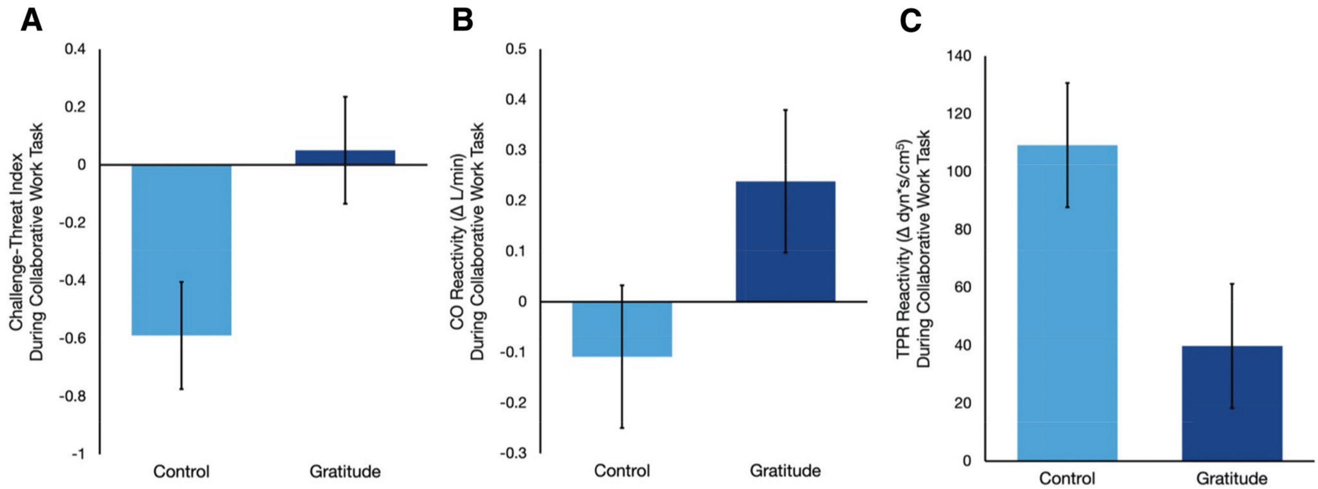
Collapsing across conditions, participants showed significantly more threat-patterned physiological responses during the collaborative work task compared with baseline, $t(173) = –2.16$, $p = .032$, 95% CI [–.52, –.02], as indicated by the challenge–threat index. Participants did not significantly differ in CO during the collaborative work task compared with baseline ($M = .14$, $SD = 1.66$), $t(174) = 1.13$, $p = .262$. Participants showed significantly higher TPR during the collaborative work task compared with baseline ($M = 74.44$, $SD = 196.45$), $t(173) = 5.00$, $p < .001$, 95% CI [45.05, 103.83].

We tested our focal hypotheses by examining how the gratitude expression manipulation impacted the challenge–threat index during stressful collaborative work. For our focal test, we used a mixed effect model to test the fixed effect of condition on the challenge–threat index, with a random intercept for dyads. As predicted, gratitude expressions ($M = .05$, $SD = 1.95$) produced less threat-patterned cardiovascular responding compared with the control condition ($M = –.59$, $SD = 1.22$), as measured by challenge–threat index reactivity, $F(1, 88) = 6.00$, $p = .016$, $b = .64$, 95% CI [.12, .64], $d = .52$ (see Figure 2A). Whereas the control condition showed threat-patterned responding on the challenge–threat index that was significantly different from zero ($b = –.59$), $t(88) = –3.19$, $p = .002$, 95% CI [–.96, –.22], the gratitude condition did not show threat-patterned responding ($b = .05$), $t(88) = .27$, $p = .786$, 95% CI [–.32, .42].

Decomposing this index into CO and TPR, we used mixed effect models to test the fixed effect of condition on CO and TPR, with a random intercept for dyads. Gratitude expressions ($M = .39$, $SD = 2.03$) produced marginally higher CO reactivity compared with the control condition ($M = –.11$, $SD = 1.13$), $F(1, 88) = 3.61$, $p = .060$, 95% CI [–.02, 1.04], $d = .41$ (see Figure 2B). We next examined whether the gratitude and control conditions individually differed from zero change using the multiple intercept form of the model: Whereas the gratitude condition produced challenge-patterned CO responding that was significantly different from zero, $t(88) = 2.11$, $p = .038$, 95% CI [.02, .78], control condition CO responding did not differ from zero, $t(88) = –.576$, $p = .566$.

Gratitude expressions ($M = 39.84$, $SD = 216.32$) generated significantly lower (less threat-patterned) TPR reactivity relative to

Figure 2
Cardiovascular Responding During the Collaborative Work Task



Note. When one member of a team expressed gratitude to the other prior to engaging in stressful collaborative work, the team members were buffered from inefficient (threat-patterned) cardiovascular responding compared with controls, as indicated by the challenge–threat index (Panel A). Gratitude expressions produced marginally improved CO (Panel B) and significantly improved TPR (Panel C). Error bars represent one standard error. See the online article for the color version of this figure.

the control condition (M = 109.05, SD = 168.56), F(1, 88) = 5.22, p = .025, 95% CI [–129.78, –9.06], d = .49 (see Figure 2C). Whereas the control condition produced threat-patterned TPR reactivity that significantly differed from zero, t(88) = 5.09, $p <$ .001, 95% CI [161.38, 217.07], gratitude condition TPR reactivity marginally differed from zero, t(88) = 1.85, p = .067.

Collaborative Work Task: Controlling for PA

One possibility is that speakers' positivity, rather than the expression of gratitude specifically, could account for the effects of condition on challenge and threat. To account for this possibility, we conducted an analysis of covariance (ANCOVA) to control for speakers' positive affect during manipulation and did not find that PA could account for the observed effects. Gratitude dyads continued to produce more challenge-patterned physiological responses compared with the control condition, as measured by challenge–threat index reactivity, F(1, 87) = 6.34, p = .014, 95% CI [.15, 1.23], d = .54. Gratitude dyads also now showed significantly higher CO reactivity, F(1, 87) = 5.19, p = .025, 95% CI [.08, 1.18], d = .49, and continued to show significantly lower TPR reactivity, F(1, 87) = 4.06, p = .047, 95% CI [–127.28, –.88], d = –.43, compared with control dyads when controlling for speakers' PA.

Individual Performance Task: PEP

As intended, the individual task elicited sympathetic arousal, indicating that the task was demanding. Collapsing across conditions, participants showed a significant decrease in PEP during the individual task compared with baseline (M = –22.11, SD = 16.64), t(171) = –17.42, $p <$ .001, 95% CI [–24.62, –9.61], d = –2.66. 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) = .32, p = .570.

Individual Performance Task: Challenge–Threat Index, CO, and TPR

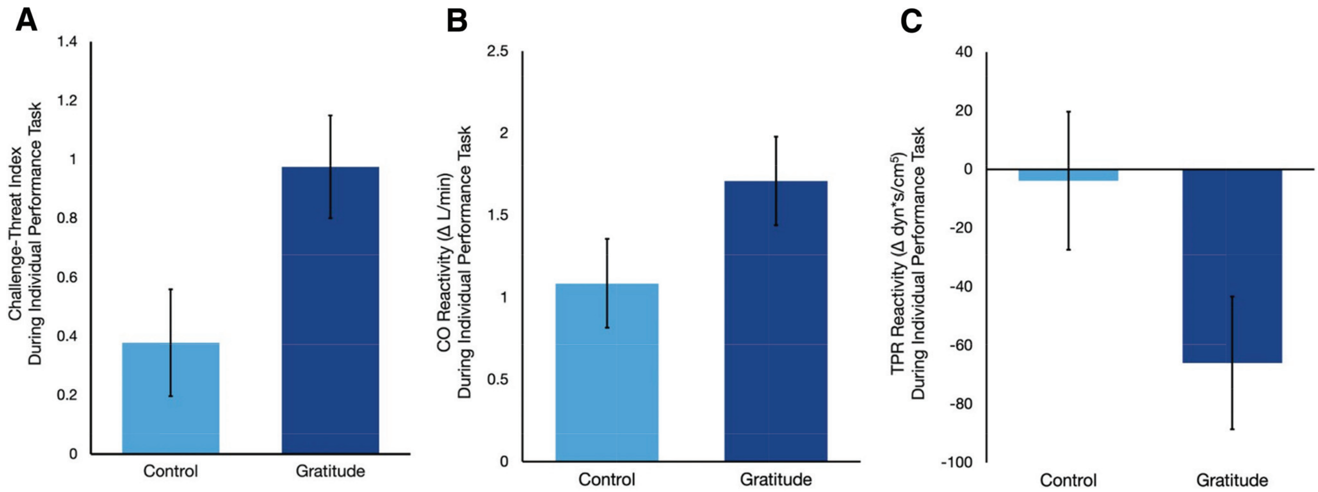
Collapsing across conditions, participants showed significantly more threat-patterned physiological responses during the individual performance task compared with baseline (M = .69, SD = 1.60), t(155) = 5.39, $p <$ .001. Participants showed significantly higher CO during the individual performance task compared with baseline (M = 1.40, SD = 2.30), t(171) = 7.96, $p <$ .001, 95% CI [1.05, 1.74], d = 1.22. Participants showed significantly lower TPR during the individual performance task compared with baseline (M = -36.12, SD = 205.97), t(155) = –2.19, p = .03, 95% CI [–68.69, –3.54], d = –.35.

For our focal test, we used a mixed effect model to test the fixed effect of condition on the challenge–threat index, with a random intercept for dyads. As predicted, gratitude expressions (M = .98, SD = 1.84) produced more challenge-patterned cardiovascular responding compared with the control condition (M = .38, SD = 1.22), as measured by challenge–threat index reactivity, F(1, 85) = 5.60, p = .020, 95% CI [.10, 1.10], d = .52 (see Figure 3). Individually, both the gratitude condition (b = .98), t(88) = 5.58, $p <$ .001, 95% CI [.63, 1.32], and control condition (b = .38), t(88) = 2.09, p = .039, 95% CI [.02, .74], showed challenge–threat index values significantly greater than zero.

The gratitude (M = 1.71, SD = 2.71) and control (M = 1.09, SD = 1.76) conditions did not significantly differ in CO reactivity, F(1, 87) = 2.66, p = .106. Both the gratitude, t(87) = 6.32, $p <$ .001, 95% CI [1.17, 2.25], and control conditions, t(87) = 4.02, $p <$ .001, 95% CI [0.55, 1.62], showed significantly increased CO relative to baseline (see Figure 3B).

Gratitude expressions (M = -65.96, SD = 236.13) generated marginally lower (more challenge-patterned) TPR reactivity relative to the control condition (M = -3.88, SD = 162.96), F(1, 85) = 3.60, p = .060. Whereas the gratitude condition produced challenge-patterned

Figure 3
Cardiovascular Responding During the Individual Performance Task



Note. Individual performance task occurred temporally further from the gratitude manipulation and when teammates were no longer actively engaged with one another. Gratitude expressing teams showed more challenge-patterned cardiovascular responding compared with controls, as indicated by the challenge–threat index (Panel A). Both control and gratitude teams showed challenge- patterned CO reactivity and did not differ from each other (Panel B). Gratitude expressions produced marginally improved TPR reactivity (Panel C). See the online article for the color version of this figure.

TPR reactivity that significantly differed from zero, $t(85) = -2.91$, $p = .005$, 95% CI [–111.09, –20.835], control condition TPR reactivity did not significantly differ from zero, $t(85) = -.16$, $p = .870$ (see Figure 3C).

Individual Performance Task: Controlling for PA

We conducted an ANCOVA to control for speakers' positive affect during manipulation, and did not find that PA could account for the observed effects. Gratitude dyads continued to produce more challenge-patterned physiological responses compared with the control condition, as measured by challenge–threat index reactivity, $F(1, 153) = 7.72$, $p = .006$, 95% CI [.14, .78], $d = .45$. Gratitude dyads also now showed significantly higher CO reactivity, $F(1, 89) = 4.43$, $p = .038$, 95% CI [.02, .70], $d = .45$, and now showed significantly lower TPR reactivity, $F(1, 153) = 4.28$, $p = .040$, 95% CI [–.67, –.02], $d = -.33$, compared with control dyads when controlling for speakers' PA.

Exploratory Analyses of Effects on Expressers Versus Receivers

The present experiment was designed and powered to test effects on dyads. However, we conducted additional exploratory tests of how the gratitude manipulation influenced expressers versus receivers. For the collaborative work task, there was neither a main effect of role (expresser vs. receiver) on challenge–threat index reactivity, $F(1, 82) = .50$, $p = .480$, nor a significant Condition × Role interaction, $F(1, 82) = 1.31$, $p = .256$. Similarly, for the individual performance task, there was neither a main effect of role (expresser vs. receiver) on challenge–threat index reactivity, $F(1, 67) = 1.69$, $p = .199$, nor a significant Condition × Role interaction, $F(1, 67) = .09$, $p = .767$. Thus, we did not find strong evidence that the gratitude manipulation influenced expressers and receivers differently. Analyses of how the gratitude manipulation impacted expressers and receivers separately are provided in the online supplemental material; we do not interpret these analyses due to a lack of power.

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' biological resources when faced with stressful tasks by eliciting 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 efficiency in cardiovascular responding—that is, an improved challenge–threat physiological stress response profile. As predicted, teammates showed improved challenge–threat responding as measured by the challenge–threat index, compared with 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: (a) when the teammates were working together collaboratively to develop a product pitch and (b) later when they independently pitched their part of the project to stoic evaluators. During the collaborative task, gratitude expressions buffered against threat responses, as indicated by the focal challenge–threat index. The control condition produced threat-patterned TPR reactivity that significantly differed from zero, whereas gratitude condition TPR reactivity was only marginally different from zero. In contrast, during the individual task, gratitude expressions amplified challenge responses, as indicated by the focal challenge–threat index. Controls showed a modest challenge response driven by myocardial influence (i.e., increased cardiac outflow) but no change in TPR, whereas gratitude expressions facilitated a challenge response consisting of both increased cardiac outflow and improved vascular response.

Importantly, both the gratitude and control conditions involved engaging in collaborative teamwork with a familiar, loose tie teammate. Further, follow-up analyses found that the expresser's positive affect during the manipulation could not account for the observed effects: When controlling for speaker's PA, the gratitude condition produced significantly improved values on the challenge–threat index, CO, and TPR during both the collaborative and individual tasks. Thus, the expression of gratitude, rather than positive affect or social support from the presence of a known other, drove the observed effects on challenge and threat. 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 coworkers), 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.

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 et al., 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 improved challenge–threat physiological responses—during a stressful task. These findings are the first of which we are aware to document physiological consequences from interpersonal gratitude. Critically, improved cardiovascular responses represent a meaningful consequence with potential translation to the challenges people face in their everyday lives.

The first finding—that gratitude buffered against biological threat responses during collaborative teamwork, as measured by the challenge–threat index—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 expressions enhanced cardiovascular efficiency later 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 min after the conclusion of the gratitude manipulation (in contrast to the collaborative work task, which occurred directly afterward); this indicates that the gratitude manipulation influenced physiological responses for at least this time period. 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.

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 responses are correlated with reduced attention to negative cues (Jamieson et al., 2013), facilitating decision making (Kassam et al., 2009), slower "brain aging" (Jefferson et al., 2010), and predict 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.

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 et al., 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 might 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 versus threat responses.

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 whether adding a team member 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. Finally, regarding the individual task, we note that the task did not involve direct interaction between teammates, and the performing teammate glanced at their partner in very few instances. However, the two teammates did sit next to one another, which raises the possibility of social influence impacting the results. And, indeed, social baseline theory suggests that the presence of others reduces threat-related neural activity (Beckes & Coan, 2011). It is possible that having the participants perform the task physically separated from their partner would produce different results, but this is a possibility that remains to be tested.

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.

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