Resting (tonic) blood pressure is associated with sensitivity to imagined and acute experiences of social pain: evidence from three studies

Tristen K. Inagaki[1] & Peter J. Gianaros[2]

[1]Department of Psychology, San Diego State University, San Diego, CA, USA

[2]Department of Psychology, University of Pittsburgh, Pittsburgh, PA, USA

In Press at Psychological Science

Author note

Tristen Inagaki https://orcid.org/0000-0002-8825-2637

Peter Gianaros https://orcid.org/0000-0003-2313-5277

We have no conflicts of interest to disclose.

Correspondence concerning this article should be addressed to Tristen Inagaki, San Diego State University, Department of Psychology, College of Sciences, 6505 Alvarado Ct., Suite 102, San Diego, CA 92182-4611. Email: tinagaki@sdsu.edu

Abstract

Social pain is a common experience with potent implications for health. However, individuals differ in their sensitivity to social pain. Recent evidence suggests sensitivity to social pain varies according to a biological factor that modulates sensitivity to physical pain: resting (tonic) blood pressure (BP). The current studies extend this evidence by testing whether BP relates to sensitivity to imagined (Study 1, *n*=762, 51% female) and acute experiences of social pain (Study 2, preregistered, *N*=204, 57% female), and whether associations extend to general emotional responding (Studies 1-3, *n*=162, 59% female). In line with prior evidence, *higher* resting BP was associated with *lower* sensitivity to social pain. Moreover, associations regarding BP and sensitivity to social pain did not appear to be explained by individual differences in general emotional responding. Findings appear compatible with the interpretation that social and physical pain share similar cardiovascular correlates and may be modulated by convergent interoceptive pathways.

Keywords: tonic blood pressure, social rejection, social disconnection, emotional dampening, interoception, hypertension

Statement of Relevance

Everybody experiences social pain – interpersonal loss, rejection, snubs, exclusion, discrimination. Indeed, social pain is an unavoidable consequence of social connection. But who is most sensitive to experiences of social pain and why remain open research questions. Combining findings from psychology, medicine, public health, and neuroscience indicating that higher resting blood pressure reduces sensitivity to acute physical pain (i.e., hypoalgesia), the present studies test whether resting blood pressure exhibits similar effects in the domain of social pain. Results indicate that higher resting blood pressure – across a broad range of resting blood pressure – is associated with lower sensitivity to imagined and acute experiences of social pain, but not general emotional responsivity. These replicated findings provide novel evidence for a cardiovascular correlate of lower sensitivity to social pain, elevated resting blood pressure, which is a leading risk factor for heart disease.

Individuals differ in their sensitivity to social pain–the unpleasant subjective experience evoked by potential or actual damage to one's sense of social connection or social value. While social pain may be a fundamental part of everyday life, it may also confer risk for poor health for some people. Hence, some describe experiences of social pain as the most negative experience of their lives (Jaremka, Gabriel, & Carvallo, 2011). And acute experiences of social pain—interpersonal loss, exclusion, rejection—often precede negative health outcomes, including cardiovascular disease (CVD), the most prevalent chronic illness worldwide (Everson-Rose & Lewis, 2005). Identifying factors that account for individual differences in sensitivity to social pain is, therefore, important for a holistic understanding of social pain and efforts to reduce the impact of such social factors on health. Based on theoretical perspectives that social pain may be processed similarly to physical pain (Eisenberger, 2012; Macdonald & Leary, 2005; Panksepp, 2004), the current studies examined associations between resting (tonic) blood pressure (BP)–an established modulator of sensitivity to physical pain–and sensitivity to social pain.

Resting Blood Pressure and Sensitivity to Physical Pain

A consistent, but perplexing, finding from the physical pain literature is the association between resting BP and sensitivity to physical pain: *higher* resting BP is associated with *lower* sensitivity to physical pain. Findings span correlational and experimental approaches, replicate across acute physical pain manipulations in animals and humans, and are seen even below thresholds for clinical hypertension (Makovac, Porciello, Palomba, Basile, & Ottaviani, 2020). Furthermore, among normotensive individuals who have not yet developed hypertension, those with (vs. without) a family history of high BP show lower sensitivity to acute physical pain, suggesting that reduced sensitivity to pain may be an early precursor to the development of hypertension (al'Absi, Buchanan, & Lovallo, 1996; France, Taddio, Shah, Pagé, & Katz, 2009). The reasons and precise mechanisms of a resting BP–pain association remain unclear. One possibility is that higher resting BP blunts the affective intensity of experiences induced by pain (e.g., Dworkin et al., 1994). By this logic, high resting BP may be functional for some acute experiences, even if there are long-term negative implications for health (e.g., clinical hypertension and consequent risk for myocardial infarction; Gianaros & Jennings, 2018).

Parallels to Sensitivity to Social Pain

Maintaining social connections throughout the lifespan is critical to survival, and short and long-term wellbeing, possibly in ways similar to physical injury (Eisenberger, 2012). Theoretical perspectives from psychology and behavioral neuroscience suggest that experiences of social pain, including monitoring for potential threats to social connection and responses to acute experiences of social pain, may thus be processed similarly to experiences of physical pain (Macdonald & Leary, 2005; Panksepp, 2004).

Primary evidence for this perspective comes from neuroimaging studies in which acute experiences of social pain elicit activity in brain regions that are also engaged by affectively distressing experience of physical pain (e.g., the dorsal anterior cingulate cortex (DACC) and anterior insula (AI); Eisenberger, 2012). For example, an acute experience of social rejection (vs. inclusion) elicits activity in the DACC and AI with greater feelings of social pain associated with greater activity in these regions (Eisenberger, Taylor, Gable, Hilmert, & Lieberman, 2007; Kross, Egner, Ochsner, Hirsch, & Downey, 2007). Medication developed to reduce physical pain likewise reduces daily feelings of social pain (Dewall et al., 2010) and greater sensitivity to acute physical pain relates to greater sensitivity to an acute experience of social pain (Eisenberger, Jarcho, Lieberman, & Naliboff, 2006).

Should physical and social pain share similar processing streams, resting BP may also be relevant for sensitivity to social pain. Consistent with this hypothesis, preliminary evidence suggests that higher resting BP, principally systolic BP, is associated with lower trait-level reports of sensitivity to social pain (Inagaki, Jennings, Eisenberger, & Gianaros, 2018; Umeda, Leutze, & Inagaki, 2021). Further, the association remains when adjusting for emotional indices also related, albeit inconsistently, to resting BP (e.g., negative affect, hostility; Inagaki et al., 2018). Whether resting BP similarly relates to responses to an acute, “in-vivo” experience of social pain, however, has not been examined.

Resting Blood Pressure and General Emotional Dampening

Further support for a resting BP-social pain association comes from conceptually related research on BP and general emotional responsivity. According to the emotional dampening hypothesis, resting BP may dampen emotional responsivity not only toward physical pain, but emotionally meaningful stimuli in general, regardless of valence (McCubbin et al., 2014). Thus, higher resting BP is linked to lower responses to an acute emotional experience (McCubbin et al. 2014; McCubbin et al., 2018) and perceived stress (Hassoun et al., 2015). Similar findings have been found for other emotional outcomes when comparing those with higher vs. lower resting BP (e.g., Duschek, Hoffmann, & Reyes Del Paso, 2017; Yoris et al., 2020). At minimum, experiences of social pain are emotional, meaningful experiences (Jaremka et al., 2011). Therefore, it could be that higher resting BP relates to less sensitivity to all emotional outcomes, including social pain. An alternative hypothesis that has yet to be systemically tested is whether resting BP exhibits unique associations with certain emotional outcomes apart from others–in this case, experiences of social pain.

Current Studies

The current studies were designed to replicate and extend preliminary findings (Inagaki et al., 2018; Umeda et al., 2021) by assessing responses to an acute experience of social pain and specificity for sensitivity to social pain. Study 1 examines associations between resting BP and sensitivity to imagined experiences of social pain using publicly available data. Study 2 is a preregistered experimental study in which participants completed a resting BP protocol followed by a paradigm to induce feelings of social pain (Cyberball). Study 3 assesses associations between resting BP and responses to an acute emotional experience. Following the literature on resting BP and sensitivity to physical pain, we expect higher resting BP to relate to lower sensitivity to imagined (Study 1) and acute experiences of social pain (Study 2). Further, we explore whether associations can be explained by those reflecting general emotional responding unspecific to social pain per se (Studies 1-3).

Study 1

Overview

Secondary data analyses were conducted on a publicly available dataset: Midlife in the United States (MIDUS Refresher): Biomarker Project, 2012 – 2016. In this part of the MIDUS study, participants completed a resting BP protocol and trait-level affective measures, including a well-known predictor of sensitivity to social pain.

Participants

The MIDUS Refresher Biomarker study obtained data from 863 respondents. After data exclusions to maintain the integrity of the resting BP and emotional measures, noted below, demographics for the analytic sample to test hypotheses (n = 762) were: M_{age} = 51.01, SD = 13.52, range = 25 – 76, 51.0% female; 3.4% Hispanic/Latinx (with 13.1% missing); 70.1% White, 7.9% Black/African American, 2.3% Native American/Aleutian, 1.4% Asian, 7.45% Other (13.3% missing).

Resting Blood Pressure

Resting BP was collected by a General Clinical Research Unit nurse or trained technician during an initial physical exam. Participants were seated for three separate BP readings. Per the MIDUS protocol description, the two most similar readings were averaged for the measure of resting BP.

A systolic (SBP) reading over 180 and diastolic (DBP) reading over 120 suggests hypertensive crisis (heart.org/bplevels). Therefore, those with mean BP readings over these thresholds were excluded from analyses (n_{SBP} = 7; n_{DBP} = 1). In addition, current smokers (n = 94) were removed from analyses as smoking blunts emotional responding (Hall et al., 2015) and there are no indications within the MIDUS protocol that participants were instructed to refrain from smoking prior to the protocol. Mean BP readings were in the elevated range: M_{SBP}: 126.74, SD = 15.65, range = 88-178, missing = 9; M_{DBP}: 77.40, SD = 9.89, range = 48-111, missing = 2. More than 50% of the sample reported taking 1 or more medications for chronic illness, including antihypertensive (35.2%) and analgesic medication (50.5%). Removing such participants would reduce statistical power and the generalizability of results to this age group (midlife adults). Therefore, we retain participants, regardless of medication status, but address these limitations in Study 2 and 3.

Sensitivity to Imagined Experiences of Social Pain: Social Anxiety

Though not the same as sensitivity to acute experiences of social pain, social anxiety – defined as fear of social experiences in which embarrassment may occur or where there is a risk of being negatively evaluated – are relevant to the current premise (e.g., Fung & Alden, 2017). Indeed, a core component of social pain is the monitoring of potential threats (including imagined future experiences) to social connection. Most relevant to current aims, individual differences in social anxiety predict how sensitive one is to imagined experiences of social pain (Breen & Kashdan, 2011), and an acute experience of social pain (i.e., Cyberball: Oaten, Williams, Jones, & Zadro, 2008). Therefore, resting BP may be associated with levels of social anxiety – with higher resting BP relating to less social anxiety.

In MIDUS, participants completed an abbreviated 9-item version of the Liebowitz Social Anxiety Scale (LSAS; Fresco et al., 2001) during which participants imagine how "painful" one feels when participating in hypothetical social experiences. Instructions were to "circle the number that best describes how much fear or anxiety [the participant] generally feel[s] in the following situations." Example social situations include going to a party; talking with people you don't know very well; expressing disagreement or disapproval to people you don't know very well. Some of the questions included in the LSAS are also included in measures that assess sensitivity to social pain, including the scale most consistently related to resting BP (Inagaki et al., 2018; Umeda et al., 2021). Feelings were rated on a 1-4 scale: 1 (none), 2 (mild), 3 (moderate), 4 (severe) scale. Responses were averaged across the 9 experiences. Higher scores indicate greater sensitivity to social pain (n = 761, missing = 1, M = 1.85, SD = .55, range = 1 – 4, ∝ = .86).

General Emotional Responding

Previous findings suggest that resting BP may dampen general emotional responding (e.g., McCubbin et al., 2014). Accordingly, associations between resting BP and additional emotional outcomes that have previously related to resting BP were assessed. These include perceived stress (Perceived Stress Scale (PSS), Cohen, Kamarck, & Mermelstein, 1983), and positive affect (Mood and Symptom Questionnaire (MASQ) – high positive affect subscale).

Data Analysis

Associations between resting BP and sensitivity to imagined experiences of social pain were evaluated with Pearson correlations in SPSS v.28. Significant associations were tested again adjusting for BMI and age – established modifiers of resting BP (Franklin et al., 1997). Parallel analyses were run linking resting BP with general emotional responding.

Non-significant associations based on p-values do not provide statistical evidence favoring the null hypothesis (Dienes, 2014). Moreover, non-significant associations (e.g., between resting BP and sensitivity to social pain or general emotional responding) could also reflect a condition wherein the data are insensitive to true associations. As noted, frequentist statistics are not suitable for inferences regarding null associations or data insensitivity. Therefore, Bayesian correlation analyses and linear multiple regression analyses were executed in JASP (JASP Team, 2020, Version 0.14.1) to further evaluate statistical associations and data sensitivity. Bayes Factors indicated as BF_{10} values reflect the probability of the alternative hypothesis, relative to the null. BF_{01} values reflect the inverse of BF_{10} values, corresponding to evidence for the null relative to the alternative hypotheses. Bayes Factors greater than 3 indicate support for hypotheses – for example, that higher resting BP is associated with lower sensitivity to social pain. Values less than .33 indicate support for the null hypothesis (for example, that the association is absent), and values between .33 and 3 indicate data insensitivity. Output from JASP for Bayesian analyses for Study 1 are posted on the Open Science Framework at: https://osf.io/vf9s2/?view_only=5d8ab5ad4693446caea9206eee76d1a4

Men displayed higher resting SBP (M = 130.54, SD = 14.50) and DBP (M = 80.16, SD = 9.77) than women (M_{SBP} = 123.09, SD = 15.87, $t(758) = 6.75$, $p < .001$, BCa 95% CI = [-9.60, -5.27], d = 15.21; M_{DBP} = 74.76, SD = 9.26, $t(758) = 7.83$, $p < .001$, BCa 95% CI = [-6.75, -4.00], d = 9.52) consistent with established literature (Ji et al., 2020). However, there were no interactions with sex when evaluating BP as a predictor of social anxiety and so analyses collapsed across sex (*p's* > .35).

Results

Resting blood pressure and sensitivity to imagined experiences of social pain

As hypothesized, higher resting BP was associated with lower anxiety or fear to imagined social experiences (i.e., lower scores on the social anxiety scale: $r_{SBP} = -.15$, $p < .001$, BCa 95% CI = [-.21, -.09]; $r_{DBP} = -.11$, $p = .004$, BCa 95% CI = [-.19, -.02]).

Bayes Factors comparing the hypothesis that higher resting BP would be associated with lower sensitivity to social pain to the null hypothesis of no association indicate strong support for the current hypothesis (Table 1).

Resting blood pressure and sensitivity to imagined experiences of social pain adjusting for BMI and age

Consistent with the current literature, BMI and age were correlated with resting BP such that higher BMI and older age were associated with higher resting BP. When adjusting for these factors, the association between resting BP and sensitivity to imagined experiences of social pain remained (r_{SBP} = -.09, p = .01, BCa 95% CI = [-.16, -.03]; r_{DBP} = -.10, p = .01, BCa 95% CI = [-.17, -.03]).

Bayesian multiple regression analyses were also conducted to compare models with BP (SBP and DBP separately) as predictors of sensitivity to social pain to a null model in which BMI and age were predictors. An uninformed uniform prior [P(M)] of 0.50 was set for each of the 2 possible models. The posterior inclusion probability values accompanying BMI suggested the variable was a poor predictor of sensitivity to social pain (PIP_{SBP} = .38; PIP_{DBP} = .50) and so the variable was dropped for better model fit. Results of this analysis suggested evidence for a regression model with SBP predicting sensitivity to social pain compared to the null model with only age predicting sensitivity to social pain (BF_{10} = 6.30, BF_{01} = .16). Similarly, the model including DBP indicated evidence for an association compared to the null with only age (BF_{10} = 6.58, BF_{01} = .15). For comparison, and given precedence in the field to account for BMI, results including BMI into the null model were: BF_{10} = 2.57, BF_{01} = .39 (for SBP); BF_{10} = 4.84; BF_{01} = .21 (for DBP).

Resting blood pressure and general emotional dampening

Resting BP has previously been associated with sensitivity to general emotional content. Indeed, higher resting SBP was linked to lower perceived stress (r_{SBP} = -.09, p = .01, BCa 95% CI [-.17, -.01]), although the association did not remain after adjusting for BMI and age (r_{SBP} = -.04, p = .27, BCa 95% CI = [-.11, .03]). Further, there were no associations between resting DBP and perceived stress (r_{DBP} = -.02) or SBP (r_{SBP} = .04) or DBP and positive affect (r_{DBP} = .02; *p's* > .29). Associations between resting BP and sensitivity to imagined experiences of social pain were stronger than most of those between resting BP and perceived stress (z_{SBP} = 1.68, p = .09; z_{DBP} = 2.32, p = .02) and positive affect (z_{SBP} = 3.25, p = .001; z_{DBP} = 2.09, p = .04). In other words, within participants, some associations were specific to sensitivity to imagined experiences of social pain.

Clarifying the non-significant associations, Bayes Factors indicate no support for an association (i.e., support for the null) between resting BP and positive affect or between resting DBP and perceived stress, but potential data insensitivity to detect a negative association between SBP and perceived stress (Table 1). Therefore, a Bayesian multiple regression analysis was carried out to compare a model with SBP as a predictor of perceived stress to a model in which BMI and age were predictors. Results of this analysis suggested SBP should be dropped as a predictor (PIP = .17). Indeed, Bayes Factors suggested no support for SBP as a predictor of perceived stress compared to a null model with BMI and age as predictors (BF_{10} = .24; BF_{01} = 4.26).

Study 2

Overview

Study 2 is a preregistered experimental study that addresses some limitations of Study 1 (https://aspredicted.org/blind.php?x=vw8a3r). In particular, participants were screened for medication status and other confounds related to resting BP or emotional responding. The protocol follows best practices for resting BP measurement in the psychophysiology laboratory setting (Shapiro et al., 1996), and extends potential associations to an acute experience of social pain.

Screening and Pre-study instructions

Recruitment occurred through an online scheduling system for research participants (SONA) for a study titled, “Individual differences in social and affective processing.” Screening criteria included age 18 years or older and enrollment in an Introductory Psychology course. Thus, participants come from a pool of young adults. Procedures were run in accordance with the University of Pittsburgh’s Institutional Review Board. All participants provided written consent prior to participation and were given 2 research credits in exchange for their time.

Participants were run between the hours of 9AM and 2PM to control for the possible influence of time-of-day effects on BP. Three days prior to the study session, participants received instructions to refrain from exercising, drinking alcohol, and taking over-the-counter medications (e.g., Ibuprofin, Claritin, etc.) at least 24 hours prior to the visit, and to refrain from drinking caffeinated beverages, smoking, and eating for at least 2 hours prior to the visit. They were also asked to wear short sleeves so that experimenters could place the BP cuff directly onto the arm (rolled sleeves can artificially increase resting BP). Compliance with pre-study instructions was assessed after written consent but prior to the start of study procedures.

Participants

Sample size of 200 was determined a priori via a power analysis in G*Power with an alpha of .01, power of .80, and a medium effect size (Cohen's *d* between .3 and .5 – based on a desired effect size). The stopping rule for data collection was to stop once we reached 200 testable participants (defined as participants who complied with pre-study instructions and completed all phases of the experimental session). The final sample included 204 individuals (56.86% female; M_{age} = 19.00, *SD* = 1.59, range from 18-34; 19.6% Asian/Asian American, 4.4% Black/African American, 68.1% White, 7.8% Other).

Resting Blood Pressure

Experimenters collected height and weight in order to calculate BMI (*M* = 23.69, *SD* = 3.90) and then placed the BP cuff over the brachial artery of the non-dominant arm, positioned at the level of the heart. Participants sat quietly for 10 minutes in order to acclimate to the lab environment and cuff. An oscillometric device (GE Dinamap PRO Monitor) was set to automatically record every 3 minutes for a total of 4 readings (i.e., 12 minutes). An average of the four readings comprised the resting BP measure following recommended best practices (Shapiro et al., 1996). Resting BP was in the normal to elevated range: M_{SBP} = 108.54, *SD* = 9.09, range = 87.75 – 137.25; M_{DBP} = 63.58, *SD* = 6.76, range = 51.25 – 94). Oral and tympanic temperature were also collected to test a different aim, but is not reported here.

Acute Experience of Social Pain: Cyberball

Participants then completed Cyberball, a computer task meant to elicit social pain (Williams et al., 2000). Participants were told that they would play the computer equivalent of ‘catch’ over the internet with two other players who were playing at other locations on campus (named Julie and Amy or David and Michael – matched to the gender of the participant). On the screen, three hands were shown in a triangle formation, with the bottom hand controlled by the participant and the other two hands controlled by the two other supposed participants. A computer ball was then thrown among the hands. When the ball landed in the participant’s hand, they could press one button to throw the ball to the player on the left and another button to throw the ball to the player on the right. In reality, the other two players on the screen were controlled by the computer and operated according to parameters set by the experimenters. Prior to playing Cyberball, participants were encouraged to immerse themselves in the game as much as possible by creating a mental picture of what might be going on during the game as if they were playing in real life (i.e., think about what the other players might look like; what sort of people they are; are you playing outside? inside?, etc.).

Participants played two “rounds” of the game – the first of which was described as a practice round to become familiar with the interface and test the internet connection. During a second round of the game, participants were first included in the game and then excluded such that the other two players continued to the throw the ball back and forth between themselves, but not to the participant.

Sensitivity to Acute Experience of Social Pain

After completing the game, participants completed a standard post-task questionnaire about their feelings of social pain in response to the exclusion round of the game (Brief Need-Threat Scale, $\propto = .87$, Williams et al., 2000). Using a 1 (not at all) to 5 (extremely) scale, participants indicated “the extent to which [they] felt the following feelings during the last round of the Cyberball (ball-throwing) game." Sample items include feeling disconnected, rejected, invisible, and liked (reversed). Higher scores indicate greater sensitivity to social pain (M = 3.59, SD = .64).

In addition, participants estimated the percentage of time they received the ball to make sure they were aware of the exclusion in the second round of Cyberball ("Assuming that the ball should be thrown to each person equally (33% if three people), what percentage of throws was directed to you during the last round of the ball-tossing game?"). All participants received a full oral and written debrief after completion of the post-task questionnaire.

Trait-level Sensitivity to Social Pain

In an attempt to replicate previous findings and following the preregistered plan, participants also completed Mehrabian's Sensitivity to Rejection (MSR) scale which assesses negative social expectations such as fear that a social interaction will result in rejection (M = 127.35, SD = 22.26; ∝ = .81, Mehrabian, 1970). Using a 1 (strongly disagree) to 9 (strongly agree) scale, participants respond to items such as: I enjoy going to parties where I don't know anyone; I am cautious about expressing my opinions until I know people quite well; I am very sensitive to any signs that a person might not want to talk to me. Negatively worded items are reverse-scored before computing the average of all 24-items. Higher scores reflect greater sensitivity to social pain.

General Emotional Responding

Finally, participants completed measures of general emotional responding that may plausibly relate to resting BP or account for any observed associations with experimentally induced social pain. Following the preregistration plan, measures included state negative affect (The Positive and Negative Affect Schedule (PANAS); *M* = 21.03, *SD* = 7.89; ∝ = .89), trait hostility (Cook-Medley Hostility Scale, *M* = 21.98, *SD* = 7.23; ∝ = .80, Cook & Medley, 1954), and perceived stress over the past month (PSS, *M* = 1.82, *SD* = .70; ∝ = .87; Cohen et al., 1983).

Data Analysis

Pearson correlations were run to assess associations between resting BP and sensitivity to social pain in SPSS v.28. Significant associations were tested again adjusting for BMI and age following the analysis approach from Study 1. Bayesian correlational analyses were also run in JASP.

According to the preregistration plan, the next analysis step was to examine the association between resting BP and sensitivity to acute social pain after adjusting for individual differences in general emotional responding and confounding health covariates. Therefore, two-stage hierarchical multiple regressions were run with sensitivity to social pain as the dependent variable. BMI, negative affect, hostility, and perceived stress, were entered at step one, followed by BP (SBP and DBP as separate regressions). Age was not specified as a covariate in the preregistration plan, but was added as a covariate to remain consistent with analyses for Study 1.

In addition to frequentist statistics, Bayesian multiple regression analyses with resting BP (SBP and DBP separately) as predictors of sensitivity to social pain were compared to null models in which BMI, age, negative affect, hostility, and perceived stress were predictors. Uninformed uniform priors [P(M)] of 0.50 were set for each of the 2 possible models.

Men displayed higher resting BP (M_{SBP} = 114.38, *SD* = 8.23; M_{DBP} = 65.51, *SD* = 7.91) than women (M_{SBP} = 104.11, *SD* = 6.98, *t*(202) = 9.631, *p* < .001, BCa 95% CI = [-12.44, -8.13], *d* = 7.54; M_{DBP} = 62.11, *SD* = 5.31, *t*(202) = 3.68, *p* < .001, BCa 95% CI = [-5.51, -1.25] , *d* = 6.56). Despite sex differences in resting BP, there were no interactions with sex in sensitivity to an acute experience of social pain, the MSR, or general emotional responding measures (*p's* > .07). Therefore, analyses collapse across sex. Data and output from Bayesian analyses conducted in JASP for Study 2 and 3 are posted on the Open Science Framework at: https://osf.io/vf9s2/?view_only=5d8ab5ad4693446caea9206eee76d1a4

Results

Replicating association between resting blood pressure and trait-level sensitivity to social pain

In replication (Inagaki et al., 2018; Umeda et al., 2021), higher resting SBP was associated with lower sensitivity to social pain, as measured by the MSR scale (*r* = -.19, *p* = .01, BCa 95% CI = [-.31, -.07]). The association remained when adjusting for BMI and age (*r* = -.16, *p* = .02, BCa 95% CI = [-.28, -.04]). Parallel associations with resting DBP were not significant (*r* = -.12, *p* = .09, BCa 95% CI = [-.26, .03]).

Bayes Factors from unadjusted correlation analyses indicated moderate evidence for higher SBP to relate to lower MSR scores, but data insensitivity to find an association between DBP and MSR scores (Table 1). Bayesian regression analyses were then conducted in order to assess the contribution of SBP to MSR scores over and above BMI and age. Options under model prior were set to uniform for the 2 possible models (P(M)] = 0.50). Comparing a model in which BMI and age predicted MSR scores to a model with SBP suggested BMI was a poor predictor and should be dropped in order to obtain better model fit (PIP = .21). After dropping BMI, the regression model with SBP predicting MSR scores suggested moderate evidence for the current hypothesis compared to the null with only age as a predictor (BF_{10} = 3.45; BF_{01} = 0.29). For comparison, Bayes Factors when adding BMI back into the model were BF_{10} = 2.72; BF_{01} = .37.

Resting blood pressure and sensitivity to acute experience of social pain

Percentage of time participants reported receiving the ball was examined as a manipulation check on the exclusion round of Cyberball. All participants reported receiving the ball less than 33% of the time, suggesting that they were aware of the rejection (M = 9.6%, SD = 5.8%). There were no associations between resting BP and the manipulation check (r_{SBP} = -.02, p = .82, BCa 95% CI = [-.16, .14], r_{DBP} = -.03, p = .73, BCa 95% CI = [-.17, .14], Table 1 for Bayes Factors) nor between the manipulation check and sensitivity to social pain (r_{MSR} = -.02, p = .83, BCa 95% CI = [-.15, .12], BF_{10} = .11, BF_{01} = 15.01; $r_{Cyberball}$ = .03, p = .71, BCa 95% CI = [-.11, .18], BF_{10} = .07, BF_{01} = 69.87).

The primary hypothesis is that resting BP will relate to sensitivity to an acute experience of social pain. As confirmation of this hypothesis, higher resting SBP was associated with lower sensitivity in response to Cyberball (r = -.21, p = .003, BCa 95% CI = [-.34, -.06]; adjusting for BMI and age r = -.17, p = .02, BCa 95% CI = [-.30, -.02]; Fig. 1). Associations between DBP and sensitivity to Cyberball were in a similar direction as those with SBP (r = -.20, p = .005, BCa 95% CI = [-.33, -.05]; adjusting for BMI and age r = -.13, p = .07, BCa 95% CI = [-.26, .00]).

Bayes Factors indicated strong to moderate associations between resting BP and sensitivity to Cyberball (Table 1). Indeed, Bayesian correlational analyses suggested resting BP is 13.19 (SBP) and 8.74 (DBP) times more likely to predict sensitivity to Cyberball than the null. The null (of no association) is only .07 (SBP) and .11 (DBP) times as likely than the alternative.

Resting blood pressure and general emotional responding

Associations between resting BP (SBP and DBP separately) and sensitivity to social pain were further evaluated after adjusting for BMI, age, and general emotional responding. Results from frequentist statistics are presented first, followed by results of Bayesian multiple regression analyses.

BMI, age, negative affect, hostility, and perceived stress accounted for 11.4% of the variance in sensitivity to an acute experience of social pain ($F(5, 197) = 5.20$, $p < .001$). Adding SBP to the regression model explained an additional 2.4% of the variance in sensitivity to social pain and this R^2 change was significant ($F(1, 196) = 5.40$, $p = .02$, Table 2). Adding DBP to a separate regression model explained an additional 1.6% of the variance in sensitivity to social pain, but this R^2 change was not significant ($F(1, 196) =$, $p = .06$, Table 3).

Bayesian regression analyses then assessed the contribution of resting BP (SBP and DBP separately) to sensitivity to social pain over and above BMI, age, and general emotional responding. For the model with SBP, BMI (PIP = .23), negative affect (PIP = .24), hostility (PIP = .62), and perceived stress (PIP = .56) were all deemed weak predictors that should be dropped in order to obtain better model fit. After dropping these predictors, the regression model with SBP predicting sensitivity to social pain suggested evidence for the current hypothesis compared to the null with only age as a predictor (BF_{10} = 4.07; BF_{01} = .25). For comparison, Bayes Factors when adding BMI and the three general emotional responding predictors back into the model were BF_{10} = 3.41; BF_{01} = .29.

For the model with DBP as the predictor of sensitivity to social pain, values indicating the posterior inclusion probability for DBP (PIP = .63), as well as BMI (PIP = .28), negative affect (PIP = .24), and hostility (PIP = .47), suggested the variables should be dropped. Indeed, keeping all predictors in the model to assess whether DBP was associated with sensitivity to social pain over and above the other variables suggested the data was insensitive to detect an association (BF_{10} = 1.57, BF_{01} = .64).

Though not specified in the preregistration plan, an additional way to probe the specificity of resting BP-social pain associations is to take the approach from Study 1 and relate resting BP with the general emotional outcomes using frequentist statistics and then test the difference between the correlations. Based on the results reported above, SBP was consistently associated with sensitivity to social pain. Therefore, analyses were constrained to SBP. Resting SBP was not associated with general emotional responding: negative affect (r = .10), hostility (r = .10), or perceived stress (r_{SBP} = -.12; p's $\geq$ .10, range of BCa 95% CI = [-.01, .08]). Further, the association between resting SBP and sensitivity to social pain was greater than parallel associations with negative affect (z = 2.77, p = .01) and hostility (z = 2.89, p = .004), but not perceived stress (z = .55, p = .58). Still, such differences further suggest some specificity for sensitivity to social pain.

Clarifying the non-significant associations between resting SBP and general emotional responding, Bayes Factors suggested evidence consistent with the null (i.e., no association between resting SBP and general emotional responding) for negative affect and hostility (Table 1). But the Bayes Factor for the association between SBP and perceived stress suggested the data might be insensitive to detect an association.

Study 3

Overview

Although there were no associations between resting BP and general emotional responding in Studies 1 and 2, this could be because participants were not responding in real-time to any emotional content as participants have in previous studies that find evidence for emotional dampening (e.g., McCubbin et al., 2014; 2018). Further, whereas the measures from Studies 1 and 2 assess sensitivity to *self-relevant* experiences of social pain in ways similar to the physical pain literature (i.e., acute physical pain is harm directed to the self), sensitivity to social pain could extend to viewing physical pain directed at others. Therefore, an exploratory analysis was conducted on an existing dataset within the lab from a separate sample of participants who completed a resting BP protocol and then responded to a task designed to induce empathy for physical pain. The task is also an acute emotional experience that is similar to those previously used to test the emotional dampening hypothesis where participants recognize the emotional experience of strangers.

Participants

Procedures (recruitment, screening, scheduling, and resting BP protocol) were similar to Study 2 such that participants came from a pool of young adults. Sample size was determined in order to test the original study's primary aims (Inagaki et al., 2018). 163 participants (M_{BMI} = 23.22, *SD* = 4.21) completed the resting BP protocol and acute emotional experience. SBP (average over four readings; *M* = 108.07, *SD* = 9.37, range = 81-134) and DBP (*M* = 63.89, *SD* = 6.43, range = 51.75-87) were in the normotensive range. Demographic information, specifically sex and age, were mistakenly left out of data collection. Information was partially recovered after data collection concluded when the error was caught in 2017. Thus, 58.9% of the sample was female (11 missing). However, experimenters were unable to verify the accuracy of the information for most participants. This means that researchers guessed the sex of participants based on name or memory, but, at the time, participants could not be contacted to confirm sex or age (e.g., participants had graduated, there was no link between the participant ID and the participant's identifying information).

Acute Emotional Experience

Participants completed a task that was originally designed to test empathy for others' experience of physical pain (Lamm, Batson, & Decety, 2007). Importantly, the task differs from the current conceptualization of social pain which, in Study 1 and 2, is focused on potential or actual damage to social connection (i.e., damage relevant to the self) as opposed to the pain of unknown strangers. Thus, participants viewed 24 brief video clips of people (12 females) making emotional facial expressions in response to aversive auditory stimulation. Clips began with a neutral facial expression (0.5s) transitioning to strong negative emotion (3.0s). Instructions were to decide how much pain the person is in with additional instructions for focusing on the affectively distressing side of the experience. In particular, participants were reminded that "there are two different aspects of pain – one is how intense or strong the pain feels, and the other is how unpleasant or disturbing it is.” Therefore, participants were instructed to focus on the second aspect of discomfort and to make ratings based on how distressed or unpleasant they thought the person was feeling using a 0-20 Gracely box scale, a validated scale used to assess experimental pain (Gracely, McGrath, & Dubner, 1978). Participants were given as much time as they needed in order to make ratings (i.e., the task was self-paced). Responses were averaged across the 24 ratings such that higher numbers indicate greater sensitivity to the task. One participant’s data was missing for this task leaving a final analytic sample of 162.

Data Analysis

Pearson correlations linking resting SBP and DBP to responses to the task were run in SPSS v.28. In order to obtain Bayes Factors for the current associations, correlation analyses linking resting BP to responses to the task were also run in JASP. Some findings from this study have been published (Inagaki et al., 2018), but results from the current task have not been published. Findings have been divided because each test related, but separate aims (i.e., an aim of the current manuscript is to assess whether associations extend to general emotional responding which departs from the previous publication). Given the exploratory nature of the current analysis and missing demographic information, we emphasize that interpretation of results should be made in view of the study’s limitations regarding age and sex. For interested readers, potential sex differences and interactions with sex are reported in Supplemental Material available online.

Results

Mean ratings to the task corresponded to “very annoying” on the scale, suggesting participants recognized the emotional experience as unpleasant for the people in the video clips (M = 11.27, SD = 3.30, range from 2.04 – 17.67, ∝ = .98). However, there were no associations between resting BP and sensitivity to the acute emotional experience (r_{SBP} = -.05, p = .56, BCa 95% CI = [-.20, .12]; r_{DBP} = -.03, p = .73, BCa 95% CI = [-.63, .11]).

Bayesian correlation analyses were run in order to clarify whether non-significant associations indicate evidence against the emotional dampening hypothesis or merely reflect insensitivity of the data to detect a true association. Bayes factors suggested moderate evidence against general emotional dampening – instead suggesting that the null hypothesis of no association is between 5.96 (SBP) and 7.56 (DBP) times more likely than the alternative (Table 1).

Discussion

The current studies show that *higher* resting BP, previously linked to sensitivity to physical pain, also relates to *lower* sensitivity to imagined (Study 1) and acute experiences of social pain (Study 2), potentially apart from general emotional responding (Studies 1,2) and pain experiences directed at strangers (Study 3). Hypothesized associations emerged across multiple measures of social pain, range of resting BP (i.e., normotensive through stage 2 hypertension) and age (18-76). Thus, higher resting BP, traditionally framed as a poor outcome (e.g., “silent killer”), may be functional under some circumstances.

Findings are consistent with re-emerging perspectives about how psychological experience might be shaped by the body. Indeed, there is renewed interest in interoception–the sense of the body's internal physiological state–as well as "body-to-mind" pathways by which afferent (visceral sensory) feedback from internal organs (e.g., heart and blood vessels) alter not only socio-emotional experiences, but also risk for chronic diseases (Gianaros & Jennings, 2018). As a source of interoceptive input, resting BP may shape the meaning ascribed to experiences of social pain, including its contextual salience and its relevance to the self, which may contribute to the global sensitivity measures in the current studies (Koban, Gianaros, Kober, & Wager, 2021). Future research is needed to test this particular causal chain of events, especially as it unfolds over time.

There are at least three, interrelated, biological pathways by which associations might occur: the baroreceptor reflex arc, vascular stiffness, and endogenous opioids. Reduced functioning of the baroreflex and increased vascular stiffness, for example, may not only impair BP control, but alter interoceptive information from the cardiovascular system conveyed to brain systems implicated in social pain (e.g., cingulate and insular cortices; Inagaki et al., 2018; Scudder et al., 2021). The central action of opioids also confers sensitivity to social pain (Inagaki, 2018) and, separately, may underlie associations between resting BP and sensitivity to physical pain (McCubbin et al., 2006). To our knowledge, these pathways are yet to be tested in relation to resting BP-sensitivity to social pain associations.

On the surface, the pattern of results might appear inconsistent with an emotional dampening hypothesis (McCubbin et al., 2014). Resting BP did not relate to hostility, positive or negative affect nor to responses to an acute emotional experience. However, the emotional dampening hypothesis proposes that resting BP will dampen the most salient emotional response in the environment–a defining feature of experiences of social pain. That is, to the extent that experiences of social pain are more meaningful (e.g., more self-relevant) than general emotional experiences, the current findings could be viewed as consistent with emotional dampening. Further, Bayes Factors indicated that while some “non-significant” associations (i.e., those based on p-values and a CI excluding 0) were inconsistent with emotional dampening, others suggested the data was insensitive to detect associations, principally those linking resting SBP with perceived stress (Study 1 and 2). Future experimental research that measures responses to multiple emotional experiences within-participants–Cyberball and tasks traditionally used to test the emotional dampening hypothesis as one example–may clarify both the emotional dampening hypothesis and the current theoretical perspective regarding cardiovascular correlates of social and physical pain.

Limitations and Future Directions

Resting BP measures were taken on one occasion. Future studies could examine BP in daily life aggregated across days for more accurate estimate. Findings are cross-sectional and therefore limit the ability to make causal conclusions. Understanding of causal direction could be helped by longitudinal research with resting BP as a predictor of real-time sensitivity to social pain (or the reverse) or pharmacological manipulation of resting BP. For instance, starting, stopping, or altering the dose of antihypertensive medication might show parallel effects on sensitivity to social pain (i.e., reducing resting BP via antihypertensive medication leading to increased sensitivity to social pain) and could be explored in future clinical trials. On a related note, more than half of the sample from Study 1 reported medication use.

Hypothesized associations emerged in Study 1 and replicated in Study 2 after screening for medication, suggesting the association is robust and potentially generalizable, but accounting for medication status is important in future research. Finally, the age range of participants in Study 2 was limited to young adults and Study 3 is limited by missing demographic information. Replication in future research inclusive of a broader age range and complete demographic information is necessary. And although findings of Study 3 help dissociate the type of pain that might be most relevant to resting BP (i.e., self-directed social or physical pain–as shown in previous literature (Makovac et al., 2020)–as opposed to the pain of strangers), additional research that assesses other experiences of social pain are necessary in order to understand boundary conditions.

A final point is about the relevance of the current findings for CVD, the leading cause of premature morbidity and mortality worldwide (Virani et al., 2020). The findings suggest the testable possibility that less sensitivity to social pain is a biobehavioral risk marker that forecasts hypertension. Whether sensitivity to social pain, as measured in the current studies, also predicts CVD outcomes such as stroke and atherosclerosis (potentially mediated or moderated by BP) when examined simultaneously with conventional psychosocial risk factors (e.g., hostility), however, remains to be tested either cross-sectionally or longitudinally. A second possibility is that sensitivity to social pain is a consequence, rather than cause, of resting BP in which case it may by an underappreciated psychological manifestation of cardiovascular physiology and pathophysiology that could be monitored and targeted in prevention and intervention efforts. Regardless of the direction of effects, the current results provide a basis to test novel hypotheses about the inter-associations between established threats to physical (hypertension) and social (social pain) health.

Fig. 1

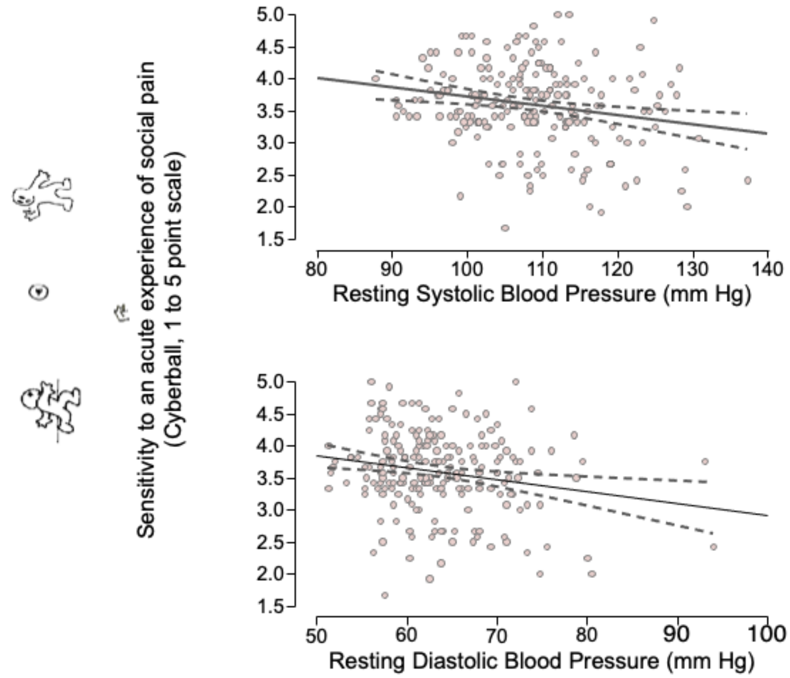

Figure 1 caption. Associations between resting blood pressure and sensitivity to an acute experience of social pain (Cyberball) from preregistered Study 2. Higher resting blood pressure (mm Hg) was associated with lower sensitivity to social pain. Association with SBP remains when adjusting for Body Mass Index (BMI), age, negative affect, hostility, and perceived stress. Dotted lines represent 95% Confidence Intervals (CI). Lower numbers on y-axes represent lower sensitivity to social pain.

Table 1
Bayes Factors from Bayesian correlation analyses linking higher resting blood pressure with lower sensitivity to socio-emotional outcomes (social pain and general emotional responding)

Variable	SBP BF_{10}	SBP BF_{01}	DBP BF_{10}	DBP BF_{01}
Study 1				
LSAS	781.327	.001	5.860	.171
Perceived Stress	2.007	.498	.067	14.935
Positive Affect	.023	42.600	.032	31.311
Study 2				
MSR	7.115	.141	.692	1.446
Sensitivity to Cyberball	13.187	.076	8.741	.114
Manipulation Check	.106	9.395	.119	8.433
Perceived Stress	.634	1.578		
Negative Affect	.044	22.592		
Hostility	.041	24.343		
Study 3				
Acute Emotion task	.168	5.964	.132	7.562

Note. LSAS = Liebowitz Social Anxiety Scale; MSR = Mehrabian Sensitivity to Rejection Scale; SBP = systolic blood pressure (mm Hg); DBP = diastolic blood pressure (mm Hg); BF_{10} = Bayes Factor in favor of the directional hypothesis that higher resting BP will be associated with lower sensitivity to social pain (or general emotional responding) compared to the null; BF_{01} = Bayes Factor in favor of the null compared to the alternative hypothesis.

Table 2
Summary of Frequentist Hierarchical Regression Analysis for Association between Resting Systolic Blood Pressure and Sensitivity to an Acute Experience of Social Pain, apart from other variables (Study 2, N = 204, 57% female)

Variable	β	*BCa 95% CI*	*t*	*R*	R^2	ΔR^2
Step 1				.337	.114	.114
BMI	-.012	[-.035, .007]	-1.086			
Age	-.091	[-.143, -.036]	-3.284*			
Negative Affect	-.002	[-.013, .009]	-.317			
Hostility	.009	[-.003, .023]	1.440			
Perceived Stress	.142	[-.014, .323]	1.894			
Step 2				.371	.137	.024
BMI	-.004	[-.026, .015]	-.352			
Age	-.084	[-.129, -.034]	-3.042*			
Negative Affect	.000	[-.012, .012]	.063			
Hostility	.011	[-.001, .025]	1.736			
Perceived Stress	.103	[-.060, .301]	1.359			
Systolic BP	-.012	[-.023, -.002]	-2.323*			

Note. BMI = body mass index; BP = resting blood pressure in mm Hg.
*$p < .05$, two-tailed, and BCa 95% CI excluding 0.

Table 3

Summary of Frequentist Hierarchical Regression Analysis for Association between Resting Diastolic Blood Pressure and Sensitivity to an Acute Experience of Social Pain, apart from other variables (Study 2, N = 204, 57% female)

Variable	β	*BCa 95% CI*	*t*	*R*	R^2	ΔR^2
Step 1				.337	.114	.114
BMI	-.012	[-.035, .007]	-1.086			
Age	-.091	[-.143, -.036]	-3.284*			
Negative Affect	-.002	[-.013, .009]	-.317			
Hostility	.009	[-.003, .023]	1.440			
Perceived Stress	.142	[-.014, .323]	1.894			
Step 2				.360	.130	.016
BMI	-.010	[-.033, .011]	-.882			
Age	-.076	[-.144, -.008]	-2.665*			
Negative Affect	.000	[-.011, .012]	.041			
Hostility	.009	[-.005, .024]	1.372			
Perceived Stress	.134	[-.026, .313]	1.805			
Diastolic BP	-.013	[-.028, .000]	-1.907			

Note. BMI = body mass index; BP = resting blood pressure in mm Hg.
*$p < .05$, two-tailed, and BCa 95% CI excluding 0.

Acknowledgements

We thank J. Richard Jennings for invaluable feedback on hypotheses and methods in this line of work and Sareen Ali, Belen Best, Kerry Owusu, and Sabine Janssen for their assistance with Study 2 and 3. Additional acknowledgements are available in Supplemental Material online.

References

al'Absi, M., Buchanan, T., & Lovallo, W. R. (1996). Pain perception and cardiovascular responses in men with positive parental history for hypertension. *Psychophysiology*, *33*(6), 655–661. doi: 10.1111/j.1469-8986.1996.tb02361.x

Breen, W. E., & Kashdan, T. B. (2011). Anger suppression after imagined rejection among individuals with social anxiety. *Journal of Anxiety Disorders*, *25*(7), 879–887. doi: 10.1016/j.janxdis.2011.04.009

Cohen, S., Kamarck, T., & Mermelstein, R. (1983). A global measure of perceived stress. *Journal of Health and Social Behavior*, *24*(4), 385–396. doi: 10.2307/2136404

Cook, W. W., & Medley, D. M. (1954). Proposed hostility and Pharisaic-virtue scales for the MMPI. *Journal of Applied Psychology*, *38*(6), 414–418. doi: 10.1037/h0060667

Dienes, Z. (2014). Using Bayes to get the most out of non-significant results. *Frontiers in Psychology*, *5*, 1 – 17. doi: 10.3389/fpsyg.2014.00781.

Dewall, C. N., Macdonald, G., Webster, G. D., Masten, C. L., Baumeister, R. F., Powell, C., … Eisenberger, N. I. (2010). Acetaminophen reduces social pain: behavioral and neural evidence. *Psychological Science*, *21*(7), 931–937. doi: 10.1177/0956797610374741

Duschek, S., Hoffmann, A., & Reyes Del Paso, G. A. (2017). Affective impairment in chronic low blood pressure. *Journal of Psychosomatic Research*, *93*, 33–40. doi: 10.1016/j.jpsychores.2016.12.008

Dworkin, B. R., Elbert, T., Rau, H., Birbaumer, N., Pauli, P., Droste, C., & Brunia, C. H. (1994). Central effects of baroreceptor activation in humans: attenuation of skeletal reflexes and pain perception. *Proceedings of the National Academy of Sciences of the United States of America*, *91*(14), 6329–6333. doi: 10.1073/pnas.91.14.6329

Eisenberger, N. I., Jarcho, J. M., Lieberman, M. D., & Naliboff, B. D. (2006). An experimental study of shared sensitivity to physical pain and social rejection. *Pain*, *126*(1–3), 132–138. doi: 10.1016/j.pain.2006.06.024

Eisenberger, N. I., Taylor, S. E., Gable, S. L., Hilmert, C. J., & Lieberman, M. D. (2007). Neural pathways link social support to attenuated neuroendocrine stress responses. *Neuroimage*, *35*(4), 1601–1612. doi: 10.1016/j.neuroimage.2007.01.038

Eisenberger, N. I. (2012). The pain of social disconnection: examining the shared neural underpinnings of physical and social pain. *Nature Reviews. Neuroscience*, *13*(6), 421–434. doi: 10.1038/nrn3231

Everson-Rose, S. A., & Lewis, T. T. (2005). Psychosocial factors and cardiovascular diseases. *Annual Review of Public Health*, *26*, 469–500. doi: 10.1146/annurev.publhealth.26.021304.144542

France, C. R., Taddio, A., Shah, V. S., Pagé, G. M., & Katz, J. (2009). Maternal family history of hypertension attenuates neonatal pain response. *Pain*, *142*(3), 189–193. doi: 10.1016/j.pain.2008.12.010

Franklin, S. S., Gustin, W., Wong, N. D., Larson, M. G., Weber, M. A., Kannel, W. B., & Levy, D. (1997). Hemodynamic patterns of age-related changes in blood pressure. The Framingham Heart Study. *Circulation*, *96*(1), 308–315. doi: 10.1161/01.cir.96.1.308

Fresco, D. M., Coles, M. E., Heimberg, R. G., Liebowitz, M. R., Hami, S., Stein, M. B., & Goetz, D. (2001). The Liebowitz Social Anxiety Scale: a comparison of the psychometric properties of self-report and clinician-administered formats. *Psychological Medicine*, *31*(6), 1025–1035. doi: 10.1017/s0033291701004056

Gianaros, P. J., & Jennings, J. R. (2018). Host in the machine: A neurobiological perspective on psychological stress and cardiovascular disease. *The American Psychologist*, *73*(8), 1031–1044. doi: 10.1037/amp0000232

Gracely, R. H., McGrath, P., & Dubner, R. (1978). Ratio scales of sensory and affective verbal pain descriptors. *Pain*, *5*(1), 5–18. doi: 10.1016/0304-3959(78)90020-9

Hall, F. S., Der-Avakian, A., Gould, T. J., Markou, A., Shoaib, M., & Young, J. W. (2015). Negative affective states and cognitive impairments in nicotine dependence. *Neuroscience and Biobehavioral Reviews*, *58*, 168–185. doi: 10.1016/j.neubiorev.2015.06.004

Hassoun, L., Herrmann-Lingen, C., Hapke, U., Neuhauser, H., Scheidt-Nave, C., & Meyer, T. (2015). Association between chronic stress and blood pressure: findings from the German Health Interview and Examination Survey for Adults 2008-2011. *Psychosomatic Medicine*, *77*(5), 575–582. doi: 10.1097/PSY.0000000000000183

Inagaki, T. K., Jennings, J. R., Eisenberger, N. I., & Gianaros, P. J. (2018). Taking rejection to heart: Associations between blood pressure and sensitivity to social pain. *Biological Psychology*, *139*, 87–95. doi: 10.1016/j.biopsycho.2018.10.007

Inagaki, T. K. (2018). Opioids and social connection. *Current Directions in Psychological Science*, *27*(2), 85–90. doi: 10.1177/0963721417735531

Jaremka, L. M., Gabriel, S., & Carvallo, M. (2011). What makes us feel the best also makes us feel the worst: the emotional impact of independent and interdependent experiences. *Self and Identity*, *10*(1), 44–63. doi: 10.1080/15298860903513881

Ji, H., Kim, A., Ebinger, J. E., Niiranen, T. J., Claggett, B. L., Bairey Merz, C. N., & Cheng, S. (2020). Sex differences in blood pressure trajectories over the life course. *JAMA Cardiology*, *5*(3), 19–26. doi: 10.1001/jamacardio.2019.5306

Koban, L., Gianaros, P. J., Kober, H., & Wager, T. D. (2021). The self in context: brain systems linking mental and physical health. *Nature Reviews. Neuroscience*, *22*(5), 309–322. doi: 10.1038/s41583-021-00446-8

Kross, E., Egner, T., Ochsner, K., Hirsch, J., & Downey, G. (2007). Neural dynamics of rejection sensitivity. *Journal of Cognitive Neuroscience*, *19*(6), 945–956. doi: 10.1162/jocn.2007.19.6.945

Lamm, C., Batson, C. D., & Decety, J. (2007). The neural substrate of human empathy: effects of perspective-taking and cognitive appraisal. *Journal of Cognitive Neuroscience*, *19*(1), 42–58. doi: 10.1162/jocn.2007.19.1.42

Macdonald, G., & Leary, M. R. (2005). Why does social exclusion hurt? The relationship between social and physical pain. *Psychological Bulletin*, *131*(2), 202–223. doi: 10.1037/0033-2909.131.2.202

Makovac, E., Porciello, G., Palomba, D., Basile, B., & Ottaviani, C. (2020). Blood pressure-related hypoalgesia: a systematic review and meta-analysis. *Journal of Hypertension*, *38*(8), 1420–1435. doi: 10.1097/HJH.0000000000002427

McCubbin, J. A., Helfer, S. G., Switzer, F. S., Galloway, C., & Griffith, W. V. (2006). Opioid analgesia in persons at risk for hypertension. *Psychosomatic Medicine*, *68*(1), 116–120. doi: 10.1097/01.psy.0000195742.24850.79

McCubbin, J. A., Loveless, J. P., Graham, J. G., Hall, G. A., Bart, R. M., Moore, D. D., … Thayer, J. F. (2014). Emotional dampening in persons with elevated blood pressure: affect dysregulation and risk for hypertension. *Annals of Behavioral Medicine*, *47*(1), 111–119. doi: 10.1007/s12160-013-9526-2

McCubbin, J. A., Nathan, A., Hibdon, M. A., Castillo, A. V., Graham, J. G., & Switzer, F. S. (2018). Blood pressure, emotional dampening, and risk behavior: implications for hypertension development. *Psychosomatic Medicine*, *80*(6), 544–550. doi: 10.1097/PSY.0000000000000598

Mehrabian, A. (1970). The development and validation of measures of affiliative tendency and sensitivity to rejection. *Educational and Psychological Measurement*, *30*(2), 417–428. doi: 10.1177/001316447003000226

Oaten, M., Williams, K. D., Jones, A., & Zadro, L. (2008). The effects of ostracism on self–regulation in the socially anxious. *Journal of Social and Clinical Psychology*, *27*(5), 471–504. doi: 10.1521/jscp.2008.27.5.471

Panksepp, J. (2004). *Affective neuroscience: The foundations of human and animal emotions*. books.google.com.

Scudder, M. R., Jennings, J. R., DuPont, C. M., Lockwood, K. G., Gadagkar, S. H., Best, B., … Gianaros, P. J. (2021). Dual impedance cardiography: An inexpensive and reliable method to assess arterial stiffness. *Psychophysiology*, e13772. doi: 10.1111/psyp.13772

Shapiro, D., Jamner, L. D., Lane, J. D., Light, K. C., Myrtek, M., Sawada, Y., & Steptoe, A. (1996). Blood pressure publication guidelines. Society for Psychophysical Research. *Psychophysiology*, *33*(1), 1–12. doi: 10.1111/j.1469-8986.1996.tb02103.x

Umeda, M., Leutze, T. M., & Inagaki, T. K. (2021). Replication and extension of the link between the cardiovascular system and sensitivity to social pain in healthy adults. *Social Neuroscience*, 1–12. doi: 10.1080/17470919.2021.1897672

Virani, S. S., Alonso, A., Benjamin, E. J., Bittencourt, M. S., Callaway, C. W., Carson, A. P., … American Heart Association Council on Epidemiology and Prevention Statistics Committee and Stroke Statistics Subcommittee. (2020). Heart Disease and Stroke Statistics-2020 Update: A Report From the American Heart Association. *Circulation*, *141*(9), e139–e596. doi: 10.1161/CIR.0000000000000757

Williams, K. D., Cheung, C. K. T., & Choi, W. (2000). Cyberostracism: effects of being ignored over the Internet. *Journal of Personality and Social Psychology*, *79*(5), 748–762. doi: 10.1037//0022-3514.79.5.748

Yoris, A., Legaz, A., Abrevaya, S., Alarco, S., López Peláez, J., Sánchez, R., … Sedeño, L. (2020). Multicentric evidence of emotional impairments in hypertensive heart disease. *Scientific Reports*, *10*(1), 14131. doi: 10.1038/s41598-020-70451-x