Biological Psychology 139 (2018) 87–95

Contents lists available at ScienceDirect

Biological Psychology

journal homepage: www.elsevier.com/locate/biopsycho

Taking rejection to heart: Associations between blood pressure and sensitivity to social pain

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ARTICLE INFO

Keywords:
Social rejection
Social disconnection
Interoception
Acute pain
Tonic blood pressure

ABSTRACT

A reliable finding from the physical pain literature is that individuals with higher resting (i.e., tonic) blood pressure experience relatively less pain in response to nociceptive stimuli. Converging lines of evidence suggest that biological factors that influence the experience of physical pain may also relate to social pain. An open question, however, is whether higher blood pressure per se is a biological factor associated with lower sensitivity to social pain. This possible association was tested in three studies. Consistent with prior findings on physical pain, higher resting blood pressure was associated with lower self-reported sensitivity to social pain across individuals (Study 1 $r = -.303$, Study 2 $r = -.262, -.246$), even after adjusting for confounding factors related to blood pressure (Study 3 $r = -.222$). Findings suggest a previously unknown biological correlate of sensitivity to social pain, providing further evidence for possible shared substrates for physical and social pain.

1. Introduction

Pain is a complex experience that can result from physical harm to the body, as well as real or anticipated harm to social relationships. Indeed, social pain resulting from social rejection, social disconnection, and other adverse interpersonal events are proposed to share similar mechanisms with those involved in experiences of physical pain (Eisenberger, 2012; MacDonald & Leary, 2005). In support of this proposal, there is evidence suggesting that brain substrates for physical pain may play a role in experiencing social pain (e.g., Eisenberger, Lieberman, & Williams, 2003). Notably, brain substrates for physical pain are reliably modulated by interoceptive (visceral sensory) information, specifically blood pressure related information conveyed from the heart and vasculature. Cumulative animal and human research spanning experimental and individual difference (correlational) approaches demonstrate specifically that higher resting blood pressure – even below thresholds for clinical hypertension – consistently relates to lower sensitivity to experiences of physical pain (e.g., electric shock, mechanical pressure, etc.) across the lifespan (for review see Bruehl & Chung, 2004). The precise mechanisms for this modulation of physical pain by blood pressure are not fully known. And, what is still entirely unknown is whether resting blood pressure relates to sensitivity to social pain. If so, then this would provide additional converging evidence for the possibility of shared mechanisms that influence physical and social pain and potentially provide a greater understanding of parallel resting blood pressure-physical pain associations.

The link between higher resting blood pressure (in the normotensive range) and blunted sensitivity to physical pain continues to be surprising and seemingly counterintuitive. Rather, it appears more intuitive to suppose that *increased*, rather than decreased, pain should be associated with *higher* resting blood pressure. Why *decreased* pain would instead be associated with *higher* resting blood pressure is more difficult to reconcile. One hypothesis is that a higher level of resting blood pressure, rather than being maladaptive, may instead be functional in some contexts (Dworkin, 1988; Dworkin, Filewich, Miller, Craigmyle, & Pickering, 1979). That is, higher resting blood pressure while experiencing painful stimuli may reduce the aversiveness of a painful experience by decreasing arousal to enable coping (Dworkin et al., 1994). Recurrent decreases in arousal during such experiences may come to reinforce higher levels of resting blood pressure over time to facilitate coping with pain (Dworkin, 1988; Dworkin et al., 1979). Thus, resting blood pressure and responses to pain may become functionally linked over time in the context of coping. As noted above, however, it is still unknown whether a similar functional association exists between individual differences in resting blood pressure and indicators of sensitivity to social pain.

Social pain – the unpleasant experience evoked by actual or potential damage to one's sense of social connection or social value – often

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https://doi.org/10.1016/j.biopsycho.2018.10.007
Received 8 August 2018; Received in revised form 2 October 2018; Accepted 7 October 2018
Available online 21 October 2018
0301-0511/

results from relationship breakups, social snubs, or the loss of close loved ones. Why might social pains 'hurt'? One possibility is that social pains are experienced as aversive because the biological mechanisms for physical pain processing were coopted by social attachment systems (Eisenberger, 2012; Panksepp, 1998). That is, monitoring and maintaining one's social relationships may be critical for well-being and survival. Consequently, the mechanisms that process and enable responses to the dangers from physical pain, including alerting one to and helping one regulate pain, may also process and enable responses to the dangers from social rejection and loss. Thus, in much the same way that physiological processes for physical pain are theorized to be functional under some circumstances, so too might physiological processes for social pain.

One line of evidence for a relationship between social and physical pain comes from neuroimaging studies in humans showing that acute episodes of social pain elicited by social rejection (Eisenberger et al., 2003) and negative social evaluation (Eisenberger, Inagaki, Muscatell, Haltom, & Leary, 2011) engage brain regions suspected to also encode the affectively distressing dimension of physical pain (dorsal anterior cingulate cortex (dACC) and anterior insula (AI)). Outside of the brain, trait levels of sensitivity to social pain reflect sensitivity to experimentally-induced social pain, such that higher self-reported levels of sensitivity to social pain are related to greater sensitivity to being socially rejected (greater self-reported distress and behavioral reaction to being socially rejected; Downey & Feldman, 1996). Furthermore, individual differences in sensitivity to a nociceptive stimulus relate to sensitivity to acute experiences of social pain. Sensitivity to physical pain (noxious heat), for example, positively correlates across individuals with sensitivity to social pain—as reflected by greater self-reported distress to an episode of social rejection (Eisenberger, Jarcho, Lieberman, & Naliboff, 2006). Accordingly, it appears plausible that experiences of social and physical pain may not only be linked with one another, but also with biological factors, such as blood pressure.

In line with this view, common brain substrates engaged by social and physical pain are involved in the regulation of blood pressure. Specifically, subdivisions of the ACC and AI cortices, as well as networked subcortical regions involved in pain, play a role in monitoring and regulating peripheral cardiovascular physiology (e.g., blood pressure) via homeostatic visceral control loops (Gianaros & Wager, 2015). Insofar as there may be shared processes and substrates between physical and social pain at the level of the brain and peripheral visceral control pathways, it is reasonable to speculate that blood pressure may also relate to aspects of social pain, including sensitivity to social pain.

Though not about social pain per se, other prominent conceptual perspectives suggest that individual differences in resting blood pressure may in fact relate to emotional responding more broadly. Thus, higher resting blood pressure has been related to reduced valence and arousal ratings of both negative and positive images from the International Affective Picture System (IAPS; Pury, McCubbin, Helfer, Galloway, & McMullen, 2004). Similar findings were observed in a separate study examining blood pressure and intensity ratings of stimuli with emotional content (sentences and facial expressions; McCubbin et al., 2014). To the extent that social pain from perceiving threats to one's social value from others is similar to emotional experiences from witnessing emotional content, then this work may further suggest a potential negative relationship between resting blood pressure and sensitivity to social pain.

The current studies therefore tested the putative association between resting blood pressure and individual differences in sensitivity to social pain. Two competing hypotheses were specifically tested based on existing literature. First, several lines of research suggest that individual differences in negative affective and psychosocial factors may relate to higher resting blood pressure (e.g., Yan et al., 2003)—although findings in this area are not uniform and may depend on the sample population, specific affective or psychosocial factor, and measurement context. Based on this literature and colloquial understanding of the link between aversive (distressing) stimuli and cardiovascular function, one hypothesis is that higher resting blood pressure will be associated with *greater* sensitivity to social pain. However, if similar biological factors influence physical and social pain, a competing hypothesis based on the literature linking higher blood pressure to lower sensitivity to physical pain and emotional responding more generally (e.g., Dworkin et al., 1994; McCubbin et al., 2014), suggests that higher resting blood pressure will be associated with *lower* (i.e., blunted) sensitivity to social pain.

To test these hypotheses, resting (tonic) blood pressure and individual differences in self-reported sensitivity to social pain were assessed in three separate samples of healthy (i.e., normotensive) individuals. Given the relative novelty of the current hypotheses, associations between resting blood pressure and individual differences in self-reported sensitivity to social pain were first assessed in two archival datasets (Studies 1 and 2) before attempting to replicate and evaluate the contributions of potential confounding variables in a new sample (Study 3). Hypotheses were not tested in any datasets, other than the three reported here.

2. Study 1

2.1. Method

2.1.1. Screening and participants

39 participants (M age = 21.82, SD = 3.42, 20 women) were studied as part of a larger protocol examining the effects of an inflammatory challenge on perceptions of the social environment. Sample size was pre-determined based on the sample size from the only other study to use an inflammatory challenge in humans published at the time (Reichenberg et al., 2001). The full procedures have been reported elsewhere (Eisenberger, Inagaki, Rameson, Mashal, & Irwin, 2009), but procedures relevant to the current aims are provided here. Potential participants were screened for general health before being enrolled in the study. Most relevant to cardiovascular measurements, participants with a BMI greater than 30, clinically meaningful abnormalities on a screening blood test, or those reporting any physical health problems or medication use were excluded. For the purposes of the current study and to minimize potential confounding effects of the inflammatory challenge, only baseline measures (before any experimental manipulation occurred) were examined. None of the measures reported here have been published elsewhere. Participants received $220 for their participation. Participants' self-identified ethnicity was 39% European–American, 18% Asian, 18% Hispanic, 7% African–American, and 18% Other. All procedures were approved by and run in accordance with the University of California – Los Angeles's Institutional Review Board.

2.2. Procedure

2.2.1. Resting cardiovascular measurement

To assess whether individual differences in resting blood pressure (BP) were associated with self-reported sensitivity to social pain, blood pressure was collected by a study nurse using an automated oscillometric device (between 8:00 and 9:35 AM) approximately 30 min after arriving for the experimental session, but prior to any experimental manipulation. To test the specificity of the association to blood pressure, heart rate (HR) was also examined. HR was collected concurrently with blood pressure. A single measurement was collected by placing the cuff around the non-dominant (left) upper arm as the participant sat in bed. In line with known sex differences (e.g., Umetani, Singer, McCraty, & Atkinson, 1998; Wolf-Maier et al., 2003), men (M = 119.79, SD = 10.856) in this sample displayed greater systolic BP (SBP) than women (M = 105.20, SD = 8.936, $t(37) = 4.592$, $p < .001$), but no sex differences emerged for diastolic BP (DBP; $t(37) = 1.859$, $p = .071$) or HR ($t(37) = .535$, $p = .596$).

2.2.2. Self-reported sensitivity to social pain

Following cardiovascular measurement, self-reported sensitivity to social pain was assessed with the Brief Fear of Negative Evaluation Scale (BFNE, $M = 2.405$, $SD = .706$, $\propto = .894$; Leary, 1983), a scale commonly used to assess sensitivity to being negatively evaluated by others. Those scoring high in fear of negative evaluation can be thought of as more sensitive to social pain, whereas those scoring lower can be characterized as less sensitive to social pain. Example items include, "I am frequently afraid of other people noticing my shortcomings" and "I am usually worried about what kind of impression I make." Ratings were made on a 1 – not at all characteristic of me – to 5 – extremely characteristic of me – scale. There were no sex differences in responses to the BFNE ($t(37) = .623$, $p = .537$).

2.2.3. Statistical analyses

To evaluate the associations of resting BP to sensitivity to social pain, primary analyses consisted of correlations to predict sensitivity to social pain from resting SBP and DBP, separately, in SPSS 24.0 (IBM SPSS Inc, Chicago, IL). Parallel ancillary models were run for HR. In addition, 95% confidence intervals (CI) were estimated using the bias corrected and accelerated percentile bootstrap method with 1000 random samples with replacement. Significance was determined at $p < .05$, two-tailed.

Given the sex differences in tonic parameters of cardiovascular physiology in the current sample, secondary analyses tested for effect moderation by sex. Thus, multiple regressions were run to predict sensitivity to social pain from resting SBP, DBP, HR, sex, and the interaction between each of these resting measures and sex. Separate models were run for SBP, DBP, and HR. No interactions between sex and resting cardiovascular measures were found (p's $> .250$).

2.3. Results

In support of the second study hypothesis, that *higher* resting BP would be associated with *lower* sensitivity to social pain, a statistically marginal and negative correlation between SBP and sensitivity to social pain was found ($r = -.303$, $p = .060$, 95% CI [−.541, −.064], Fig. 1). There was no statistical association between DBP and sensitivity to social pain ($r = .186$, $p > .250$, 95% CI [.002, .145]). Furthermore, there was no statistical association between HR and sensitivity to social pain ($r = .162$, $p > .250$, 95% CI [−.177, .354]), suggesting a more consistent influence of SBP as a predictor variable. Indeed, the correlation between SBP and sensitivity to social pain differed from the correlation between DBP and sensitivity to social pain ($z = 2.785$, $p = .005$) and HR and sensitivity to social pain ($z = 2.154$, $p = .031$).

These findings for SBP, as compared with DBP and HR, seem to agree with those from the physical pain literature, wherein SBP has been more consistently associated with blunted pain sensitivity (see Discussion). However, the sample size and particular measure of sensitivity to social pain may have influenced these observations. In Study 2, we aimed to replicate and extend this initial finding from Study 1 using a larger sample of participants and an additional self-report measure of sensitivity to social pain.

3. Study 2

3.1. Method

3.1.1. Screening and participants

For Study 2, 115 participants (69 women, M *age* = 24.17, $SD = 6.61$), screened for general health via the same procedures as Study 1, were invited to participate in a larger study on the effect of an inflammatory challenge on social experience. Study details have been reported elsewhere (Moieni, Jevtic, Irwin, Breen, & Eisenberger, 2015), but the data and analyses conducted as part of the current manuscript have not been published. Sample size for Study 2 was pre-determined based on a compromise between the desire to detect condition differences on the primary outcomes of interest (neural and genetic outcomes) and issues of per participant protocol costs. As in Study 1, data from the baseline assessments, before any experimental manipulation occurred, were evaluated to test the current hypotheses.

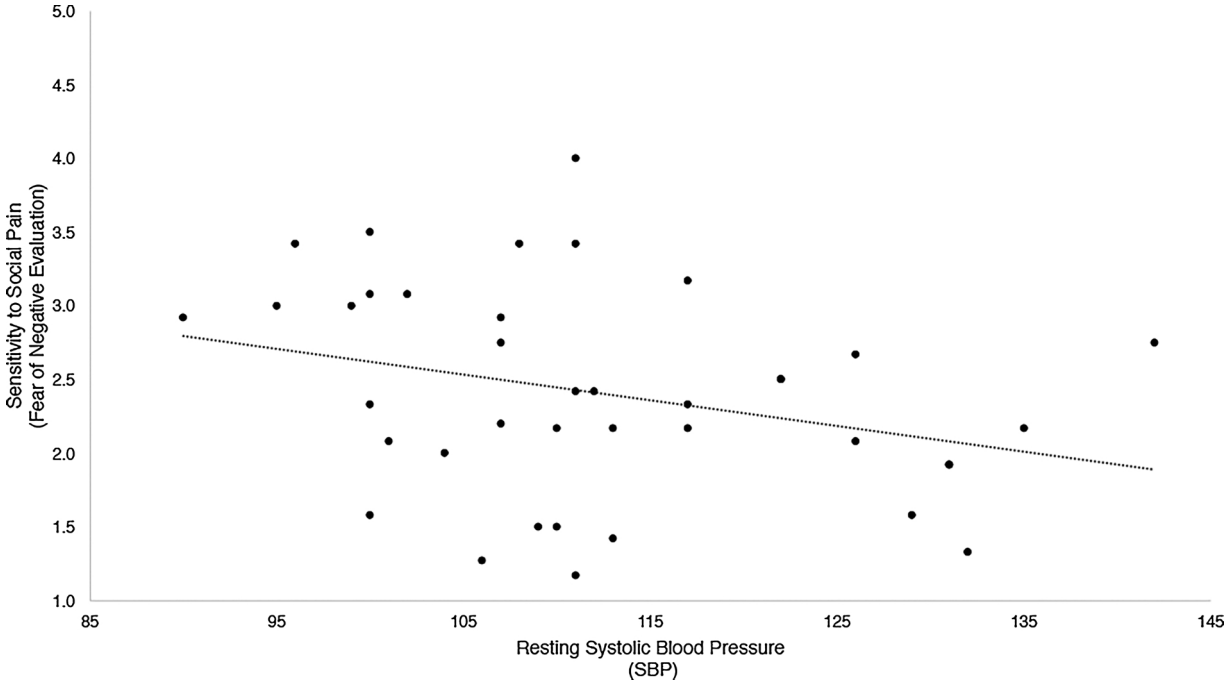

Fig. 1. Negative correlation between resting systolic blood pressure (SBP) and sensitivity to social pain from Study 1. Higher SBP was marginally associated with lower self-reported sensitivity to social pain (N = 39, r = −.303, p = .060, 95% CI [−.541, −.064]). Lower numbers on self-reported sensitivity to social pain (Brief Fear of Negative Evaluation Scale) represent less sensitivity to social pain.

3.2. Procedure

3.2.1. Resting cardiovascular measurement

Resting BP and HR were collected in the same manner as Study 1. Data for one participant with an SBP (SBP = 79) 3 SD's below the mean was removed from the sample. This resulted in an analytical sample of 114 participants. Results held with the outlier included.

Men displayed greater SBP (M = 115.826, SD = 9.063) and DBP (M = 79.978, SD = 10.184) than women (M SBP = 108.397, SD SBP = 8.06, $t(112) = 4.590$, $p < .001$; M DBP = 73.250, SD DBP = 8.923, $t(112) = 3.730$, $p < .001$), consistent with the literature on sex differences in BP (e.g., Umetani et al., 1998; Wolf-Maier et al., 2003). In this sample, men (M = 64.065, SD = 8.818) exhibited lower HR than women (M = 69.750, SD = 8.354; $t(112) = 3.485$, $p = .001$).

3.2.2. Self-reported sensitivity to social pain

As in Study 1, sensitivity to social pain was assessed with the BFNE scale (M = 2.580, SD = .798, $\propto$ = .909). In addition, participants completed Mehrabian's Sensitivity to Rejection (MSR) scale (M = 4.045, SD = .608, $\propto$ = .712; Mehrabian, 1970, 1994), which assesses perceptions of negative social expectations, including fear that interactions will result in rejection or discomfort (Mehrabian, 1994) (the MSR measure was not included in Study 1). Using a 1 (strongly disagree) to 7 (strongly agree) scale, participants indicated the extent to which they agreed with statements such as "I sometimes take criticism too hard," "If someone dislikes me, I tend to avoid him/her," and "I am very sensitive to any signs that a person might not want to talk to me." To obtain a sensitivity to social pain score for each participant, negatively worded items were reverse-scored before computing the average of the negatively and positively worded items (Mehrabian, 1970, 1994). Lower scores reflect lower self-reported sensitivity to social pain.

In the current sample, there were no sex differences in BFNE scores ($t(113) = 1.142$, $p = .256$). However, women reported higher MSR scores (M = 4.159, SD = .620) than men (M = 3.874, SD = .554, $t(113) = 2.514$, $p = .013$).

3.2.3. Statistical analyses

Correlations between SBP and sensitivity to social pain (BFNE and MSR separately), DBP and sensitivity to social pain, and HR and sensitivity to social pain were computed separately in SPSS v.24. Bootstrapped confidence intervals (95%) were also computed using the bias corrected and accelerated percentile bootstrap method using 1000 samples with replacement. Once again, interactions between sex and resting cardiovascular measurements were evaluated when predicting sensitivity to social pain, but no such interactions were found (p's > .350). Similarly, there were no interactions between sex and MSR scores when predicting resting parameters of cardiovascular physiology (p's > .250) and so analyses collapsed across sex. Significance was determined at $p < .05$, two tailed.

3.3. Results

Consistent with the literature on BP and sensitivity to physical pain and replicating the trend from Study 1, SBP was negatively correlated with BFNE scores (Table 1). Similarly, SBP was negatively correlated with MSR scores (Fig. 2). That is, *higher* SBP was associated with *lower* self-reported sensitivity to social pain.

In this sample, higher DBP was also associated with lower BFNE ($r = -.185$, $p = .049$, 95% CI [−.374, .001]) and MSR scores ($r = -.265$, $p = .004$, 95% CI [−.442, −.071]). However, HR was not statistically associated with either scale (with BFNE: $r = .129$, $p = .170$, 95% CI [−.056, .310]; with MSR: $r = .077$, $p = .418$, 95% CI [−.093, .242]). As in Study 1, the correlation between SBP and sensitivity to social pain was different from the correlation between HR and sensitivity to social pain (BFNE: $z = 3.050$, $p = .002$; MSR: $z = 2.506$, $p = .012$), again suggestive of a comparatively more consistent effect of SBP.

Table 1
Associations between resting systolic blood pressure (SBP) and self-reported sensitivity to social pain.

		∝	r	p	95% CI
Study 1					
	BFNE	.894	−.303	.060	[−.541, −.064]
Study 2					
	BFNE	.909	−.262	.005	[−.400, −.108]
	MSR	.712	−.246	.008	[−.449, −.012]
Study 3					
	BFNE	.884	−.097	.222	[−.250, .069]
	MSR	.764	−.222	.005	[−.365, −.069]

Note: BFNE = Brief Fear of Negative Evaluation (Leary, 1983); MSR = Mehrabian Sensitivity to Social Rejection (Mehrabian, 1970, 1994).

The consistency of the negative association between resting SBP and sensitivity to social pain across two different samples and two different scales suggests initial support for current hypotheses. However, resting BP is a multi-determined parameter of physiology known to relate to a number of other psychosocial factors that may be conceptually related to sensitivity to social pain (e.g., hostility, negative affect, neuroticism), as well as anthropometric, physical-health, and methodological factors. Therefore, Study 3 was run to explore the contribution of such variables possibly related to BP and to implement a more rigorous methodological approach for BP measurement.

4. Study 3

4.1. Method

4.1.1. Screening and participants

163 participants (96 women, but sex was mistakenly not collected from 11 participants) were recruited from the Psychology Subject Pool in exchange for 2 research credits. Sample size was determined via GPower* (Faul, Erdfelder, Buchner, & Lang, 2009). Using an ∝ of .01, a power of .80, and a medium effect size (*Cohen's d* between .3 and .5), we determined a sample size of 150 participants would be sufficient to detect associations between BP and sensitivity to social pain. Therefore, we aimed to collect a sample of 150 usable participants. Data collection stopped at the end of the semester after we had reached at least 160 participants (e.g., to guard against the possibility that participants might not follow pre-study instructions or the possibility of data loss due to technical difficulties). For the raw data, see https://osf.io/c7jtq/.

Inclusion criteria required participants to be 18 years or older and a student in Introductory Psychology. Following recommended best methodological practices for the measurement of BP (Shapiro et al., 1996), participants were excluded if they indicated that they were taking prescription medications or had any condition that required a prescription medication (e.g., antihypertensive medication). 48 h prior to their scheduled session, participants also received an email instructing them not to drink caffeinated beverages, smoke, or eat at least two hours before their session. Further, participants were asked to refrain from exercising, drinking alcohol, and taking over-the-counter anti-inflammatory medications (e.g. Ibuprofin, Claritin or other allergy medications) at least 24 h before their session. Finally, participants were asked to wear short sleeves so that the brachial BP cuff could be placed directly on the arm (rolling long-sleeves may artificially raise BP because of vascular constriction). Compliance with pre-study instructions was assessed prior to initiating the resting cardiovascular measurement protocol. Questionnaires from a single participant were lost due to a technical error and so results are based on a final sample of 162 participants. The University of Pittsburgh's Institutional Review Board approved all procedures.

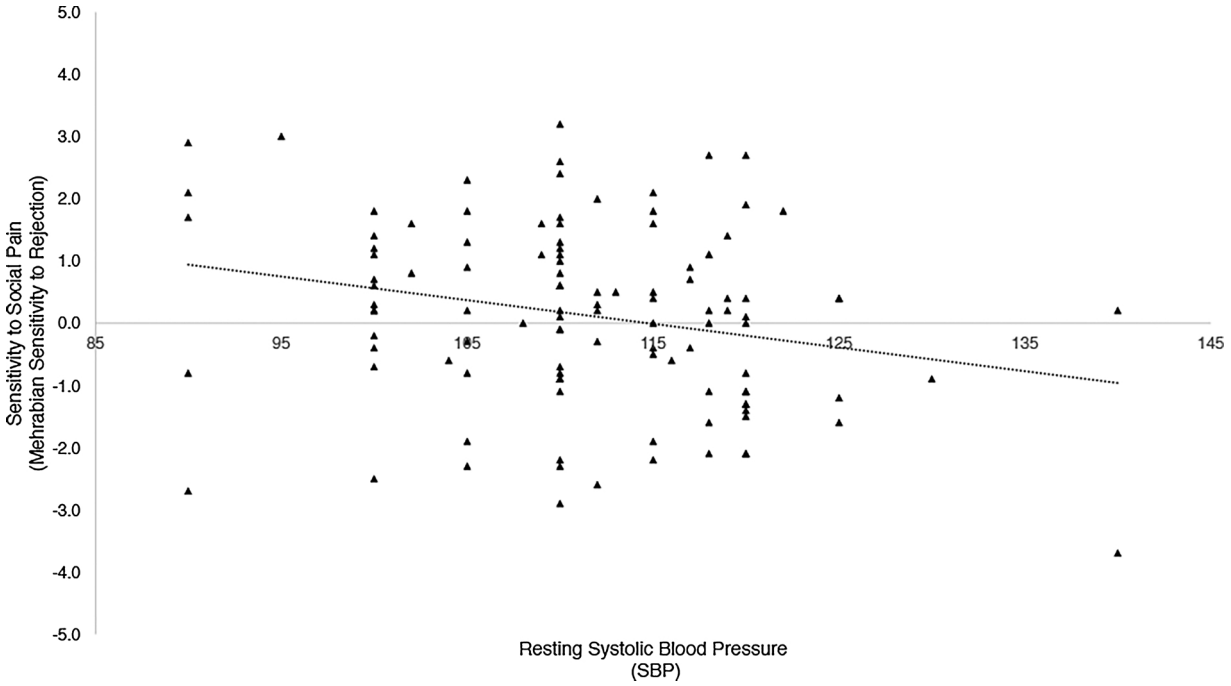

Fig. 2. Association between resting systolic blood pressure (SBP) and sensitivity to social pain (as measured by Mehrabian's Sensitivity to Rejection scale) from Study 2. Higher SBP was associated with lower self-reported sensitivity to social pain (n = 114, r = −.246, p = .008, 95% CI [−.449, −.012]). Lower numbers on sensitivity to social pain represent less sensitivity to social pain.

4.2. Procedures

Participants were scheduled to attend a lab session between the hours of 9am and 2 pm (to control for BP fluctuations as a function of the sleep-wake cycle; Smolensky, Hermida, Castriotta, & Portaluppi, 2007). Upon arrival to the lab, experimenters collected height and weight (to calculate BMI) followed by resting BP and HR, and finally self-reported sensitivity to social pain and psychosocial covariates.

In Study 3, men had greater SBP (M = 112.335, SD = 9.308) than women (M = 105.188, SD = 8.609, $t(150) = 4.791$, $p < .001$), but there were no sex differences for DBP (M *men* = 64.348, SD = 7.160; M *women* = 63.620, SD = 6.225, $t(150) = .658$, $p < .250$). As in Study 2, men had lower HR (M = 66.286, SD = 9.572) than women (M = 72.464, SD = 10.279, $t(150) = 3.665$, $p < .001$).

4.2.1. Resting cardiovascular measurement

To obtain resting BP and HR, participants first sat quietly in a private room for 10 min in order to acclimate to the lab setting. The experimenter then fit the participant with a cuff placed over the brachial artery of the non-dominant arm (positioned at the level of the heart). Measurements were taken with an oscillometric device (GE Dinamap PRO Monitor) set to inflate every 3 min during the resting period (approximately 12 min to obtain 4 readings; Shapiro et al., 1996). To obtain a global measure of resting BP and HR, an average of the 4 time points was created. This compares with the single measurement of BP and HR taken in Studies 1 and 2, facilitating a reduction in measurement error.

4.2.2. Self-reported sensitivity to social pain

As in Study 2, participants completed the BFNE (M = 2.137, SD = .470, $\propto$ = .884) and MSR scales (M = 4.305, SD = .594, $\propto$ = .764). There were no sex differences in responses to the BFNE scale ($t(149) = .726$, $p = .469$), but as in Study 2, women had higher MSR scores (M = 4.384, SD = .593) than men (M = 4.119, SD = .564, $t(149) = 2.701$, $p = .008$).

4.2.3. Health and psychosocial covariates

To evaluate the strength of the association between BP and social pain, physical health and psychosocial factors that are suspected or known to relate to resting BP were evaluated as covariates. Specifically, BMI (Pi-Sunyer, 1993), state negative affect (The Positive and Negative Affect Schedule (PANAS), Watson, Clark, & Tellegen, 1988), hostility (Cook-Medley Hostility Scale, Cook & Medley, 1954), neuroticism (Eysenck Personality Questionnaire (EPQ), Eysenck & Eysenck, 1975), Type D personality (Type D Scale-14, Denollet, 2005), perceived stress (Perceived Stress Scale (PSS), Cohen, Kamarck, & Mermelstein, 1983), depression (Center for Epidemiological Studies Depression (CES-D) Scale, Radloff, 1977), and anxiety (State-Trait Anxiety Inventory (STAI), Spielberger, Gorsuch, & Lushene, 1971) were collected. Indeed, BMI (Eckel & Krauss, 1998; Field et al., 2001)), negative affect (Jonas & Lando, 2000), neuroticism (Spiro, Aldwin, Ward, & Mroczek, 1995), Type D Personality (Denollet, 2005), perceived stress (Dimsdale, 2008), hostility, depression, and anxiety (Gallo & Matthews, 2003), have all been implicated as risk factors for hypertension and thus, elevated resting BP.

4.2.4. Statistical analyses

The association between resting BP and sensitivity to social pain were evaluated with correlations for the BFNE and MSR scales separately. Significant associations were then tested again adjusting for other health and psychosocial factors that may relate to BP. Specifically, BMI was included as a physical health covariate and negative affect, hostility, neuroticism, Type D personality, perceived stress, depression, and anxiety were included as psychosocial covariates. Two-stage hierarchical multiple regressions were conducted in SPSS v.24, with sensitivity to social pain as the dependent variable. BMI, negative affect, hostility, neuroticism, Type D personality, perceived stress, depression, and anxiety were entered at step one, followed by resting cardiovascular measurements. In addition, the association between resting HR and sensitivity to social pain was examined as before in Studies 1 and 2. Significance was determined at $p < .05$, two-tailed. A marginal interaction between sex and resting HR for the BFNE scale was found ($p = .060$), but no other interactions were found

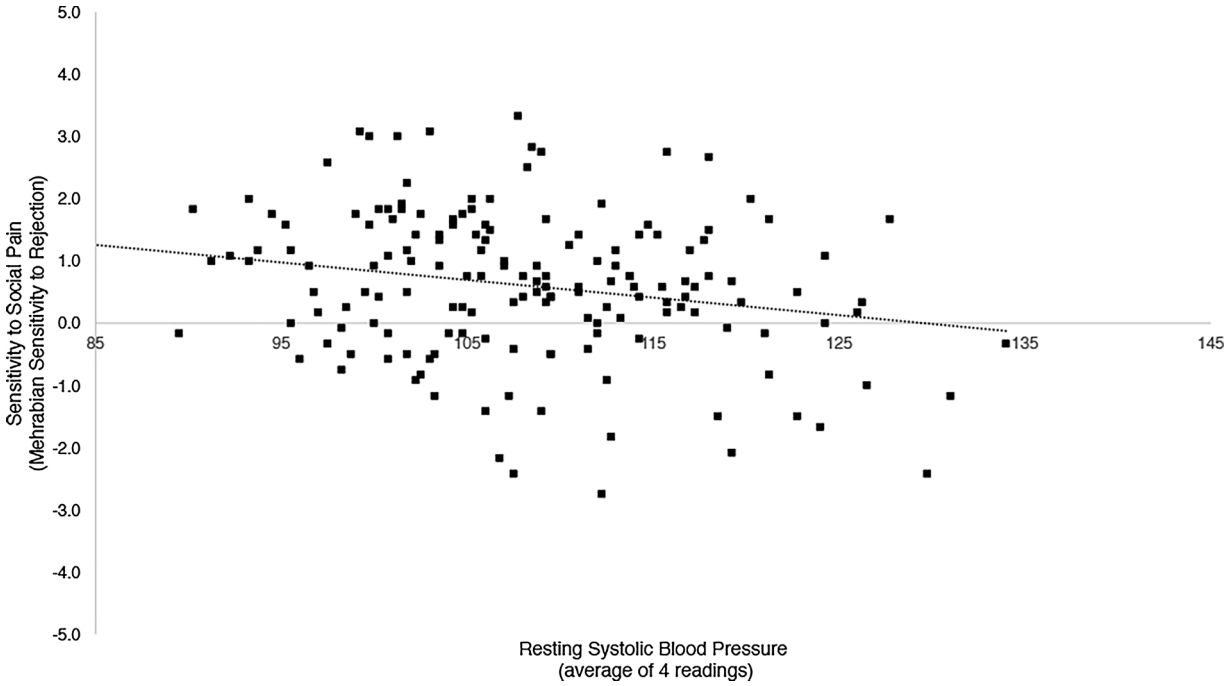

Fig. 3. Association between resting systolic blood pressure (SBP) and sensitivity to social pain from Study 3. Replicating Study 1 and Study 2, resting SBP was negatively correlated with self-reported sensitivity to social pain, such that higher resting SBP was associated with less sensitivity to social pain, as measured by self-reports to Mehrabian's Sensitivity to Rejection scale (n = 162, r = −.222, p = .005, 95% CI [−.365, −.069]).

(p's > .150) and so sex was omitted from further analyses.

4.3. Results

In Study 3, the association between SBP and BFNE was in the hypothesized direction, but was not significant (Table 1). However, SBP was negatively correlated with MSR such that higher SBP was associated with lower scores on the MSR (Fig. 3). In other words, higher resting SBP was associated with lower self-reported sensitivity to social pain.

There was no statistical association between resting DBP and sensitivity to social pain (BFNE: r = .064, p = .419, 95% CI [−.100, .234]; MSR: r = .017, p = .829, 95% CI [−.136, .194]) nor between HR and social pain (BFNE: r = −.027, p = .733, 95% CI [−.193, .139]; MSR: r = .077, p = .332, 95% CI [−.085, .230]). Once again, the correlation between SBP and social pain (as measured by the MSR scale) was significantly different from the correlation between HR and social pain (z = 2.721, p = .007). In a pattern similar to Study 1, the correlation between SBP and social pain was again significantly different from the correlation between DBP and social pain (z = 3.138, p = .002), suggesting a comparatively stronger effect of SBP.

The association between resting SBP and MSR was then evaluated adjusting for potential confounding factors. Hierarchical multiple regression revealed that BMI, state negative affect, hostility, neuroticism, Type D personality, perceived stress, depression, and anxiety accounted for 22.3% of the variance in MSR (F(10, 151) = 4.49, p < .001, Table 2). Adding SBP to the regression model explained an additional 2.1% of the variance in MSR and this R^2 change was significant (F(11, 150) = 4.16, p = .043).

4.3.1. Association between resting SBP and sensitivity to social pain across Studies 1–3

Using Fisher r-to-z transformations, we averaged the three univariate correlations between resting SBP and indicators of sensitivity to social pain across all studies (Study 1 r = −.303, N = 39; Study 2 average of associations with BFNE and MSR r = −.254, n = 114; Study 3 r = −.222, n = 162). The mean z_r = −.266. After back transformation, the mean r-value across studies was −.260 (95% CI [−.39, −.12]), corresponding to a small effect size.

Table 2
Summary of Hierarchical Regression Analysis for Variables Predicting Resting Systolic Blood Pressure (SBP) from Study 3.

Variable	β	t	R	R^2	ΔR^2
Step 1			.48	.23	.23
BMI	−.09	−1.22			
Negative Affect	.08	.98			
Hostility	−.05	−.54			
Neuroticism	.23	1.99*			
Type D Personality-Negative Affect	−.47	−3.26*			
Type D Personality-Social Inhibition	.20	2.28*			
Type D Personality-Negative Affect × Social Inhibition	.13	1.61			
Perceived Stress	.10	.83			
Depression	−.18	−1.50*			
Anxiety	.47	3.23*			
Step 2			.50	.25	.02
BMI	−.02	−.27			
Negative Affect	.09	1.10			
Hostility	−.04	−.48			
Neuroticism	.23	2.00*			
Type D Personality-Negative Affect	−.48	−3.34*			
Type D Personality-Social Inhibition	.21	2.40*			
Type D Personality-Negative Affect × Social Inhibition	.12	1.59			
Perceived Stress	.07	.57			
Depression	−.16	−1.38			
Anxiety	.46	3.13*			
Mehrabian Sensitivity to Rejection	−.16	−2.04*			

* p < .05.

A meta-analysis on the primary associations, adjusting for covariates (BMI and neuroticism, the covariates collected across all three studies) was also run using Comprehensive Meta-Analysis version 3. Analyses were set to average the two effects in Study 2 (BFNE and MSR) to avoid violating independence assumptions of measures derived from the same sample, leaving the number of effect sizes in the analysis to

$k = 3$. There was no heterogeneity in the 3 effect sizes ($Q(2) = .623$, $p = .732$, $I^2 = .000$, Tau-squared = .000), thus both the random-effects model (assuming heterogeneity in effect sizes) and fixed effects model (assuming homogeneity in effect sizes) were identical. Analyses revealed that the overall effect size was significant ($d = .18$, 95% CI [.066, .285], $z = 3.108$, $p = .002$) suggesting that across these three studies, resting SBP was negatively correlated with sensitivity to social pain after adjusting for BMI and neuroticism.

5. Discussion

Pain can be felt in response to both physical and social harm due to their potentially shared mechanisms. The current studies extended the well-known link between higher resting BP and decreased sensitivity to physical pain to the domain of social pain. We show that individuals with higher resting BP – most consistently SBP – report less self-reported sensitivity to social pain. Furthermore, the association between resting SBP and sensitivity to social pain replicates across three separate samples. The current findings merge and extend two previously separate theoretical perspectives: (1) the potential functional link between resting BP and sensitivity to physical pain and (2) the theory that physical and social pain relate to similar biological factors or share similar biological substrates.

Though seemingly counterintuitive, the current findings follow the long-standing association between BP and sensitivity to physical pain (Bruehl & Chung, 2004) and recognition of emotional stimuli (McCubbin et al., 2014; Pury et al., 2004). The former specifically suggests that higher, rather than lower, BP may have functional significance for both physical and social pain (Dworkin, 1988; Dworkin et al., 1979). Hence, BP may serve a regulatory function by blunting sensitivity to pain, potentially making pain more tolerable. Although causation cannot be determined based on the current results alone, evidence from experimental animal models support a mechanistic (causal) association between higher resting BP and decreased sensitivity to physical pain. For instance, pharmacologically increasing BP (vs. placebo) causes less pain-related responding to noxious stimuli (less running from noxious electric shock; Dworkin et al., 1979). Similarly, experimentally increasing BP decreases sensitivity to painful stimuli in humans (e.g., hammer to the Achilles tendon; Dworkin et al., 1994). Thus, BP appears to causally affect sensitivity to physical pain. Whether BP also causally affects sensitivity to social pain remains open for future inquiry.

Of note is the correlational nature of the current findings. Resting SBP was associated with self-reported sensitivity to social pain, but whether resting blood pressure causally influences sensitivity to social pain or the reverse requires additional experimental methods. For example, future experimental work that manipulates BP during experiences of social pain would help determine whether BP also causally influences sensitivity to social pain. Furthermore, the existing literature on BP and sensitivity to physical pain assesses sensitivity to acute or experimentally-induced physical pain challenges (Bruehl & Chung, 2004). However, another limitation of the current studies is the focus on trait level individual differences in sensitivity to social pain. Although these studies represent a preliminary step in understanding the functional significance of the link between BP and sensitivity to social pain, an important next step for this line of work will be to extend the current findings to test associations between BP and acute or experimentally-induced responses to social interactions that might lead to social pain (e.g., perceived discrimination during interracial social interaction, distress to social rejection). Finally, although the aggregate pattern of results suggests a resting BP – social pain association, correlations between resting BP and social pain (specifically BFNE scores in Study 1 and Study 3) did not uniformly reach conventional levels of statistical significance. This pattern of results provides a basis for further replication attempts, more precise estimation of effect sizes, and the boundary conditions under which resting BP relates to social pain within and between people.

One outstanding question from the current results is *how* resting BP and pain may become negatively linked in this way. Although the pathways that link higher resting BP with sensitivity to physical pain continue to be explored, we elaborate here on two plausible pathways based on existing human and nonhuman animal literatures: (1) the endogenous opioid system and (2) the baroreceptor reflex arc. We note, however, that these are neither exhaustive explanatory pathways nor are they mutually exclusive as candidate mechanisms potentially linking blood pressure and social pain. For example, an additional possibility is that features of blood pressure control and sensitivity to social pain could be related because of convergent processes mediated by brain circuits that are jointly involved in the processing of affective information and visceral control (e.g., anterior cingulate cortex, insula; cf., McCubbin et al., 2014).

To elaborate on the first possible pathway, endogenous opioids may be a common pathway through which resting BP, physical pain, and social pain are regulated. Indeed, opioids have long been examined in relation to the regulation of cardiovascular (Holaday, 1983), physical pain (Millan, 1986), and social pain responding (Panksepp, 1998). For instance, naltrexone, an opioid antagonist that blocks naturally occurring opioid activity, increases feelings of social disconnection, a correlate of sensitivity to social pain, both in the lab and in daily diary reports (Inagaki, Irwin, & Eisenberger, 2015; Inagaki, Ray, Irwin, Way, & Eisenberger, 2016). That is, blocking opioids may increase sensitivity to social pain. Furthermore, the negative relationship between resting BP and sensitivity to physical pain reverses after naltrexone administration, such that sensitivity to physical pain likewise increases (Bruehl et al., 2010). It is possible that opioid pathways also mediate the relationship between resting BP and sensitivity to social pain. However, pharmacological manipulations of the opioid system are needed to clarify the contribution of opioids to the link between resting BP and social pain.

Visceral sensory information regarding BP is relayed to the brain on a heart beat-to-beat basis via specialized interoceptors, called baroreceptors (Gianaros & Wager, 2015). Many baroreceptors have their sensory endings positioned within the heart and major blood vessels, and they are maximally stimulated during systole—when the heart is contracting and when pressure against vessel walls is greatest (Garfinkel & Critchley, 2016). Interoceptive information from the baroreceptors reaches the brain via the vagus and glossopharyngeal nerves, where this information normally serves to maintain BP homeostasis via negative-feedback mechanisms implemented by the autonomic nervous system (i.e., rises in BP trigger autonomic reflexive effects that lower future BP) (Gianaros & Jennings, in press). In addition to these autonomic and homeostatic effects, interoceptive information about BP conveyed by the baroreceptors, particularly during systole, has been shown to modulate (e.g., blunt) sensitivity to nociceptive stimuli and even affect sensitivity to affective information, such as fear stimuli (Berntson, Sarter, & Cacioppo, 2003; Garfinkel & Critchley, 2016). Moreover, directly manipulating afferent baroreceptive input to the brain appears to exert direct effects on physical pain processing, and other psychological processes (Dworkin et al., 1994).

In view of the above, it is notable that across the three studies, blunted sensitivity to social pain appeared to be more consistently associated with SBP compared with DBP. Indeed, as compared with both DBP and HR, the magnitude of the association between SBP and sensitivity to social pain was consistently stronger. SBP, DBP, and HR are not interchangeable parameters of cardiovascular physiology. Moreover, SBP, DBP, and HR may be viewed as different parameters of interoceptive physiology that may bear on the interpretation of the present findings. Hence, systole and diastole comprise the two phases of the cardiac cycle, respectively corresponding to the contraction and relaxation of the heart. As commented above, ascending interoceptive traffic to the brain is greatest during systole, when peak pressure (SBP) is achieved by the contraction of the heart and ejection of blood into the

aorta and peripheral vasculature. During systole, the visceral afferent baroreceptors are maximally stimulated. HR itself is an end-organ product of efferent (visceral motor) outflow of the sympathetic and parasympathetic arms of the autonomic nervous system to the sinoatrial node. Although there are no known interoceptors for monitoring HR per se, as there are for blood vessel distention caused by pressure changes (i.e., the baroreceptors), HR is a major determinant of cardiac output. As a result, HR is an indirect determinant of BP. The present work precludes strong inferences about the possibly separable associations between sensitivity to social pain and SBP vs. DBP.

In speculation, however, it may be that SBP is a more reliable correlate of sensitivity to social pain because it reflects or more reliably encodes information about visceral afferent (interoceptive) influences on physical pain and social pain processing. In addition to exploring opioid pathways, the latter postulate may be testable using experimental designs that directly manipulate different parameters of cardiovascular physiology and baroreceptor function. That is, the relative importance of systole vs. diastole may be empirically falsifiable to the extent that presentation of social pain stimuli during these phases of the cardiac cycle may evoke different subjective responses or different encoding, as suggested by the literature on physical pain and emotion processing (Garfinkel et al., 2014; Gray, Rylander, Harrison, Wallin, & Critchley, 2009).

In conclusion, three studies provide initial evidence that the relationship between resting BP and sensitivity to physical pain extends to the domain of social pain. Those with higher resting BP also report lower sensitivity to social pain, possibly suggesting a functional link between cardiovascular physiology and pain. The results add to an existing body of evidence that suggests that physical and social pain might share biological substrates and extends this evidence base to the cardiovascular system.

Acknowledgements

Thank you to Rebecca Ferrer who provided valuable statistical guidance and the following for their assistance with data collection and study coordination for Study 3: Laura Hazlett, Sareen Ali, Kerry Owusu, Jaswitha Basu, Nikita Karulkar, and Amanda Sauer. Study 1 was supported by a NARSAD Young Investigator Award, a Dana Foundation grant, a UCLA Faculty Senate Grant, and a postdoctoral research fellowship (T32-MH19925) to N.I.E. Study 2 was supported by an R01 from NIMH (5R01MH091352).

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