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REVIEW

No pain, no social gains: A social-signaling perspective of human pain behaviors

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Abstract

In this review article, we describe a social-signaling perspective of human pain and pain empathizing behaviors which is based on the premise that pain percepts evolved to serve both intrapersonal as well as interpersonal, communicative functions. This perspective offers a generative framework for understanding the natural origin and proximate expression of felt pain and pain empathizing behaviors. The basic thesis is that humans evolved sensory-behavioral heuristics for perceiving and inhibiting exogenous and endogenous pain sensations as part of more general expressive styles characterized by the demonstration of vulnerability gestures (*i.e.*, trustworthiness cues) versus empowerment gestures (*i.e.*, capacity cues), and these styles ultimately facilitate broader self-protection and social novelty-seeking life-history behavior strategies, respectively. We review the extant literature on how social contextual factors (*e.g.*, audience characteristics) and how structural and functional components of individual's social network appear to influence the expression of pain behaviors in ways that support basic predictions from the social-signaling perspective. We also show how the perspective can be used to interpret conventional findings of sex differences in pain percepts and pain empathizing behaviors and for predicting how the situational context and individual's peer networks modulate these differences *in vitro* and *in vitro*. We conclude the article by describing how pain researchers may better understand how varying levels and divergent directions of changes in affect tend to co-occur with systematic changes in internal *vs* external pain sensitivities, and thus why, from an evolutionary perspective, pain may occur in the presence and absence of physical tissue damage.

Key words: Pain behaviors; Psychology; Social support; Sex differences; Communication

Core tip: This article introduces a social-signaling perspective of pain and pain empathizing behaviors, which hypothesizes that both exogenous and endogenous pain percepts evolved as part of more general expressive heuristics for demonstrating basic trait impressions (*e.g.*, empowerment *vs* vulnerability cues) to different types of affiliates. Prototypical sex differences in pain sensitivity/empathizing may then reflect specialized expressive styles for regulating distinct relationship dynamics throughout humans' natural history. We show how the perspective accounts for several findings on how social contextual factors (*e.g.*, audience characteristics) and how structural and functional components of the individual's social network appear to influence contemporary pain expression.

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INTRODUCTION

Scientists and health providers are currently limited in

their knowledge of many biopsychosocial processes that constitute a pain experience and how people subjectively evaluate pain suffering in others. Sensory pain perception is influenced by, and modulated through, processes that involve tissue stress and damage (*e.g.*, physical disease and injury), peripheral and central nociception (*i.e.*, afferent input and brain processing), mental thoughts (*e.g.*, memories), emotions, and social settings[1,2]. Pain empathizing is similarly influenced by automatic (unintentional, reflexive) and controlled (intentional, reflective) reactions that are based on behavior and cognitive appraisals of the pain sufferer, trait attributes of the pain observer/pain sufferer, and situational factors in the immediate social context[3-7]. Clinically, the reciprocal nature of the relationship between patient pain experiences and pain empathizing reactions of others forms the cornerstone of patient pain reports, health provider decision-making, and overall patient treatment quality.

A handful of contemporary pain theorists have independently derived similar conceptual models for predicting individual and group differences and circumstantial variability in the experience and expression of pain. These models have been referred to by various names, including "social communication"[8], "socio-relational"[9], and "social transactional" models of pain[10,11], but they all rest on the general premise that humans experience pain and pain empathizing feelings/sensations in part to signal important social information to other people. This social-signaling perspective of pain perception and pain empathizing behaviors offers a generative framework for understanding the natural origin and proximate expression of these phenomena. The perspective uniquely focuses on the behavioral functions of pain percepts that originate from either exogenous (*e.g.,* skin abrasion) or endogenous sources (*e.g.,* muscle aches, menstrual pain, headaches) within a broader framework of human expressive behaviors.

In this review article, we provide a selective overview of the social-signaling perspective of pain perception and show how it can be used to predict how social contextual factors (*e.g.,* audience characteristics) and social environmental factors (*e.g.*, social network structure) influence exogenous (*e.g.*, experimental) and endogenous (*e.g.*, somatic) pain sensitivity. The framework is also generative for predicting situational- and environmental-modulation of sex differences in clinical and experimental pain reports and pain empathizing responses. We conclude the article by describing future conceptual directions from a social-signaling perspective, with a particular emphasis on ways to better understand how varying levels and divergent directions of changes in affect tend to co-occur with systematic changes in internal *vs* external pain sensitivities, and thus why, from an evolutionary perspective, pain may occur in the presence and absence of physical tissue damage.

SOCIAL SIGNALING MODEL OF PAIN

The degree to which felt pain is viscerally experienced (*i.e.*, subjective pain intensity) is only measurable *via* pain behaviors such as facial grimaces, distinct body movements, and verbal reports[11,12]. Recent applications of advanced neuroimaging techniques have led to claims that felt pain intensity can be objectively measured with this technology alone[13,14]. Still, these studies are dependent on verbal reports of pain to assess the veracity of their outcome measures. Therefore, what pain researchers and treatment providers are largely measuring are pain behaviors and not painful sensations or pain percepts per se. The fact that felt pain is most evident and (arguably) conceptually and pragmatically relevant, as a behavior begets the plausibility that pain percepts evolved to serve both intrapersonal, as well as interpersonal, communicative functions.

At the most basic level, exogenous pain sensations serve the same basic, intrapersonal functions as all external sensory perceptual systems (*e.g.*, visual, auditory, olfactory, gustatory, tactile) that enable the individual to detect and discriminate certain types of stimuli in the environment. External pain sensations are also functional as an environmental warning system, by demanding attentional resources and promoting self-awareness (*e.g.*, to attend to and protect an injured body-part), and for facilitating operant learning (*e.g.*, to avoid dangerous stimuli[15,16]). However, these basic intrapersonal functions do not explain why, from an evolutionary perspective, humans experience deep-tissue endogenous (*e.g.*, somatic) pain sensations that originate from within the body, often in the absence of physical tissue damage, that can neither be avoided, easily remedied, or directly learned from in and of themselves.

Instead, it makes more sense that the tendency for humans to experience endogenous pain percepts evolved so that the individual will modify their general activity levels and produce pain behaviors that signal salient social information, such as momentary vulnerability versus prowess, to other people *via* the presence or absence of pain gestures. Exogenous pain percepts are also able to provide such information, but they are distinct from intrinsic discomfort because external pain tends to occur during voluntary activities (*e.g.*, during physical labor, acts of bravery, acts of aggression) and hence under situations in which the individual usually has some degree of control. This distinction is important because it suggests that external and internal pain percepts have slightly different social signaling functions, with the latter being unavoidable, and therefore, better able at conveying sincere trait impressions (honest signaling) of the individual's current state of debilitation than may be possible *via* external pain behaviors. Finally, both external and internal pain percepts serve the functions of allowing the individual to assess the reliability and dependability (solicitousness tendencies) of other social agents in their environment. Each of these interpersonal functions can be characterized as communicative in nature, because they are modulated (*i.e.*, resulting in differential expression) by factors in the immediate social context, by factors in the individual's broader social environment, and by the individual's affec-

tive functioning, which tends to correspond to changes in perceived social-standing[9].

EVOLUTION OF HUMAN EXPRESSIVE BEHAVIORS

Detailed models for explaining how and why the social context and individual's affective functioning influence pain and pain empathizing behaviors can be understood within the context of a broader framework on the evolution of human expressive behaviors. According to Vigil's Socio-Relational Framework of Expressive Behaviors (SRFB[9]), all forms of heuristical expressive behaviors including discrete gestures that demonstrate "positive" *vs* "negative" affect (facial expressions, body movements, verbal reports, *etc.*) and gestures that demonstrate the presence or absence of felt pain evolved to modulate *(i.e.*, attract or avert) social interactions with other people. This occurs *via* the selective signaling of one or both of the two most parsimonious properties of human "reciprocity potential", or interpersonal value to other people. These constructs can be conceptualized as: (1) demonstrations of prowess, empowerment, and ultimately capacity cues, which exhibit one's ability to reciprocate with others; and (2) demonstrations of appeasement, vulnerability, and ultimately trustworthiness cues, which establish that one is non-threatening and willing/likely to reciprocate with others[9,17]. Humans are predicted to continuously exploit both positive and negative life experiences and conditional circumstances along with the situational context for the opportunity to demonstrate these two basic trait impressions to other people.

For example, people heuristically respond to stochastic events that enhance the perception of one's capacity attributes (*i.e.*, enhanced material and/or social resources; experiential prosperity) with gestures the demonstrate empowerment cues to others (*e.g.*, verbal and nonverbal expressions of joy, confidence, lower pain). In contrast, humans respond to events that detract from or diminish ones' capacity attributes (*i.e.*, material and/or social losses; experiential adversity) with gestures that demonstrate vulnerability (*e.g.*, sadness and depression) and ultimately trustworthiness cues to other people[18-21]. This is because, under these latter conditions, the individual is less effective at conveying capacity impressions and should, therefore, utilize stochastic adversity and particularly repeated and uncontrollable hardships, and hence circumstances that the individual cannot escape or avoid, as an opportunity to advertise genuine (*i.e.*, honest-signaling) states of debilitation and compromise, and ultimately trustworthiness cues, to other people.

The SRFB also predicts that humans direct and utilize capacity gestures (*e.g.*, expressed joy and confidence) and trustworthiness gestures (*e.g.*, expressed sadness) to influence different types of relationship partners and to maintain different types of social network structures. Specifically, people are predicted to selectively direct capacity cues toward novel, prospective, and hence riskier affiliates such as acquaintances and strangers[9,17]. This is because affiliative, capacity attributes such as trait-happiness are highly attractive to prospective peers and are therefore effective at increasing the absolute number of reciprocators that individuals are likely to interact on the daily basis (see also[18]). Increasing the size of one's social sphere necessarily limits the amount of time that can be devoted to individual relationship partners, and capacity traits (*e.g.*, physical prowess) are easier to verify than trustworthiness traits (*e.g.*, trait-kindness) through brief interactions with others. Capacity traits are also more indicative of the ability to provide expedient (*e.g.*, one-time) rather than continuous resources to others (*e.g.*, a mating opportunity, physical protection, interchange of socio-political or material resources). Finally, gestures that demonstrate capacity attributes (*e.g.*, facial expressions of joy, quick and open body movements) are more discernable from a distance than trustworthiness gestures (*e.g.*, facial sadness, slow movements). Collectively these patterns support the thesis that: humans evolved the behavioral heuristic to advertise higher levels of capacity gestures when they possess larger, less intimate (*e.g.*, time-investing), and more fluid peer networks and for maintaining these types of network structures, and thus when having a higher number of affiliates necessarily limits the amount of time that can be used to influence individual relationship partners[9,17,18].

In contrast, people are predicted to direct trustworthiness cues (*e.g.*, expressed sadness and insecurity) toward intimate, continuous, and hence dependable affiliates such as family and close friends, and hence the types of relationship partners who are most likely to provide remedial social support to the individual in times of need[9,18,22]. When individuals are experiencing vulnerability they tend to avoid less familiar and hence riskier affiliates and to express behaviors (*e.g.*, head bow, gaze aversion, expressed insecurity) that effectively dissuade interactions with these types of people[23], ultimately resulting in the formation of smaller, more consolidated, and more secure peer networks. Moreover, the fact that trustworthiness impressions (*e.g.*, kindness, loyalty, prosocial motivations) require repeated interactions to effectively convey and to evaluate in other people, and the tendency for these types of cues to be more indicative of the probability of reciprocating continuous rather than expedient resources (*e.g.*, anticipated emotional and logistical assistance) support the thesis that: humans heuristically advertise higher levels of trustworthiness gestures when they possess smaller, more exclusive peer networks; and for maintaining these types of network structures[9,18].

In other words, by responding to adversity with behaviors that operate to consolidate one's social network, the individual is able to avert interactions with less familiar and hence riskier affiliates while simultaneously spending more time with intimate and co-dependent relationships partners. The expression of vulnerability cues is also functional for providing these latter types of affiliates with the opportunity to project altruism and hence reciprocal

demonstrations of trustworthiness cues back towards the vulnerable individual, ultimately strengthening the dependability of individual's most intimate relationships. In essence, these "socio-relational" principles can be summarized by the omnibus thesis that humans evolved the behavioral heuristic to advertise empowerment cues (*e.g.*, expressed joy) in ways that promote a broader social novelty-seeking behavior strategy, whereas humans instead utilize vulnerability cues (*e.g.*, expressed sadness) to potentiate a self-protection behavior strategy[9,18,24].

Evolution of pain-signaling behaviors

Thus, from the perspective of the SRFB, the behavioral expression of external and internal pain percepts, being pinnacle forms of vulnerability gestures, can be viewed as natural kinds of trustworthiness cues. Pain empathizing behaviors, being pinnacle examples of altruistic gestures, can similarly be viewed as distinct types of trustworthiness cues. In this sense, the human occurrence when pain is expressed and responded to by others can be viewed as a symbiotic transactional process in which people interchange reciprocal demonstrations of trustworthiness cues with intimate (*i.e.*, reliable and trusted) relationship partners[8,9,10,25]. The idea that momentary vulnerability and altruism gestures share an underlying social-signaling function explains why for example people with higher trait empathy also show higher experimental pain sensitivity[26]. The contra hypothesis, of course, is that pain concealment, pain tolerance, and hypoalgesia can operate at a social-signaling level to convey empowerment and hence capacity cues to other people. Similarly, the lack of pain empathizing behaviors, at least in theory, may be interpreted as part of an expressive style characterized by the inhibition of compromise and expressed altruism and thus as the projection of capacity cues in and of itself. According to the SRFB[25], the tendency to heuristically express pain intensity and pain empathizing for advertising core components of human reciprocity potential (*i.e.*, capacity or trustworthiness cues) were set in cognition early in the course of human evolution.

Sex differences in expressive styles

Evolutionary psychology theories of sex differences in expressive styles, including sex differences in the expression of pain behaviors[25-27] have attributed the differences to the unique sub-ecologies in which ancestral males and females evolved. These ecologies can be understood from an evolutionary history of male-male coalitional competition and male-biased philopatry (also referred to as patrilocality or female exogamy). In this type of social system, males tended to remain in closer proximity to their male kin, thus allowing them to form secure, kin-based coalitions, while females tended to emigrate into the social networks of their husbands upon marriage, which was historically upon the timing of sexual maturation (*i.e.*, during adolescence[28]). Greater reliance upon non-kin and more distantly-related affiliates (particularly upon adolescence) would have constrained females to develop higher cognitive thresholds for trusting peers as well as heightened motivations for forming fewer, more time-invested and intimate peer relationships. These proclivities would seem necessary for increasing the reliability of their relationships in the absence of inclusive fitness (*i.e.*, shared genes[29-31]). From the perspective of the SRFB, such inclinations would have also co-evolved with the general heuristic for females to demonstrate higher levels of altruistic tendencies and vulnerability displays (*i.e.*, non-threat), and hence trustworthiness cues than males on average, thereby allowing females to strengthen the reliability and security of their peer relationships[9,18]. This general thesis explains the conventional pattern of women reporting quantitatively and qualitatively (*e.g.*, menstrual pain) dimorphic pain experiences, including higher experimental and clinical pain sensitivity, along with higher levels of pain empathizing behaviors than men on average[26,32-35].

In unison, a social-signaling perspective is useful for predicting how various social factors influence the expression of pain (*e.g.*, verbal reports) in home, clinical, and research settings. The basic premise of this approach is that the patterns in which people express pain and pain empathizing are partly governed by behavioral heuristics outlined by the SRFB[9,25]. To date, three basic hypotheses have been testing when concerning the social-signaling of pain: (1) Males and females express different levels of pain and pain empathizing behaviors; (2) The immediate social context influences felt pain; and (3) Structural and functional components of individuals' social networks are linked to felt pain. These hypotheses are discussed in the following three consecutive sections.

SEX DIFFERENCES IN PAIN AND PAIN EMPATHIZING

It is well-established that biological sex modulates pain behaviors. As compared to males, females report greater prevalence, frequency, and duration of clinical pain and pain-related distress[35-39]. Women also differ in their actual pain experiences when compared to men with women experiencing more internal pain events (*e.g.*, headaches, stomach cramps, menstrual cramps) as oppose to men who experience more external pain events (*e.g.*, concussion, broken extremity, physical violence[40]). Experimental studies show that women report lower pain threshold and tolerance, and higher pain intensity associated with various types of noxious stimuli (*e.g.*, ischemic, pressure, electrical, and thermal[32,34,36,38,41]. The magnitude of these group differences varies from moderate to large depending on sample size, nature of the stimulus, and whether pain sensitivity is indexed by threshold or tolerance[27,32,34,36,41]. Sex differences in pain behaviors have also been detected as early as infancy[42,43], and in both adults and in infants, the behavioral differences exist despite no clear evidence of associated sex differences in neurocortical responses to pain[44]. Females have also been observed as showing a stronger correlation between facial displays and subjective

pain intensity[45], which is perhaps more consistent with the hypothesis that males may inhibit the expression of pain behaviors, rather than the alternative possibility that females instead exaggerate the expression of pain.

Finally, it is important to note that females experience qualitatively different types of pain than males, including a variety of discomfort sensations that are associated with menstruation. Developmental research shows that sex differences in pain experiences, depression, and somatic symptoms correspond to the timing of pubertal transition in adolescent girls, more so than in same-aged boys; females experience rapid increases in depressive symptoms and self-reported distress upon puberty as compared to the relatively constant rates among boys[46-48]. Sex differences in negative affect peak in early adulthood and then decline slowly but continue to exist throughout middle and late adulthood[49-52]. These patterns are consistent with a human natural history of male-biased philopatry and the SRFB[9] which predict that female emigration to the social environments of their husbands upon marriage required heightened tendencies for demonstrating trustworthiness cues to non-kin upon this stage in life. Still, it is important to note that, although this framework provides a plausible explanation of the epidemiology of higher pain sensitivity in biological females as compared to males on average, it does not fully account for additional factors, such as gender identity, which may partly influence external pain perception irrespective of biological (*i.e.*, chromosomal) sex. Several studies have found, for instance, within-sex variability in concomitants of gender identity such as sexual orientation and self-rated levels of dispositional masculinity/femininity are predictive of pain sensitivity[53-55].

Experimental research shows that females report higher pain empathizing behaviors than males on average, for example, when asked to rate the pain levels of other people experiencing discomfort and distress in their physical presence[6,23]. There is also some preliminary support that patient treatment may be influenced by their health-provider's gender. Studies have found that female physicians are more likely than male physicians to prescribe higher doses of analgesics to underserved categories of patients such as ethnic minorities and other females[56,57].

People tend to show distinct brain activation when they experience pain empathy, which corresponds to the so-called "pain-matrix"[58,59], yet only a few studies have found sex differences in empathy-related neurocortical activity[60-63]. Other studies have not found these differences[57,64-66], and there is some research that suggests that males and females show distinct patterns of associations between empathy-related brain functioning and behavioral indicators of empathy. Females show a stronger association between neurocortical and verbal indicators of pain empathizing than males[67], while males tend to be more critical than females in their evaluations of others, which may attenuate neurocortical empathetic responses[68]. Thus, while the extant research shows that females are more likely to express felt pain and pain empathizing behaviors than males on average, this research also suggests that these differences are modulated by situational factors (*e.g.*, interpersonal appraisal processes) in the immediate social context.

SITUATIONAL VARIABILITY IN PAIN BEHAVIORS

Experiments have shown that active interaction with, and even the passive presence of others in the immediate social context influence subjective and autonomic pain responses[69,70]. Observational studies show that people express heightened pain behaviors (*e.g.*, intensity reports and facial expressions) in the presence of intimate affiliates such as a significant other or parents during standard medical procedures[71-75]. Instead, interactions with a non-deferential, unfamiliar, and more authoritative person preceding a pain task results in hypoalgesia[76,77]. Even infants have been shown to respond to the social context, for instance, by expressing lower pain behaviors in the presence of a dismissive parent[78]. These findings are consistent with the SRFB thesis that pain should be expressed most intensely in the immediate presence of intimate and familiar relationship partners (*e.g.*, family, significant other), because these types of affiliates are most likely to provide solicitous reactions toward the pain sufferer, and that interactions with less intimate, non-deferential, and unfamiliar people should instead predict inverse expressions[25].

Likewise, the SRFB predicts that there should be systematic differences in the effects of male versus female audiences/targets on momentary pain percepts. Because women naturally form fewer, more intimate (*i.e.*, time-consuming and investing), and more exclusive relationships[9,17,29,79] and demonstrate higher levels of parental investment and pain empathizing behaviors than males on average[6], people are predicted to demonstrate greater pain sensitivity (*e.g.*, hyperalgesia) in the immediate presence of other women than in the presence of men[25]. This prediction has been met with mixed support which suggests that the role of observer's gender on pain percepts is contingent on a multitude of factors. For example, several experiments have shown that people are more likely to demonstrate heightened exogenous pain sensitivity when they are processed by a female researcher[77,80,81]. In our lab, we found that even minimal procedural interactions with female personnel (*e.g.*, processing consent procedures and explaining the research protocol) can lead to heightened experimental pain reports, particularly in women, even when the noxious stimuli is experienced in solitude, without the actual physical presence of another person[82]. In another study, we found that the absolute number of female (strangers) but not males present during an ischemic pain task is linearly associated with hyperalgesia in women only[6]. In contrast, there is some research that suggests that females may actually experience hypoalgesia in the immediate presence of a (real or simulated) male[83]. This makes sense, given that men are

less likely to display empathy than females[6], and thus offer less solicitous reinforcement for other people to express pain in their presence compared to the benefits of expressing pain to females.

The impact of the presence of women on the momentary pain intensity levels of men appears to be more dynamic. Our lab and others have found that, in men only, the presence (or simulated presence) of female researchers or other female strangers during an experimental pain test (*e.g.*, cold pressor, ischemic) results in hypoalgesia[84,85]. Other research has demonstrated that this hypoalgesic effect in linearly related to the absolute number of female strangers in the room during the pain task[6]. Thus it appears that among healthy young males, the presence of female strangers produces a hypoalgesic effect, although the opposite pattern (hyperalgesia in the presence of a female researchers) has also been reported[77,80]. Clinical studies instead show that solicitous spousal responses are associated with increased pain behaviors[86,87], and as we have found in our own lab (unpublished data), males in particular tend to report greater debilitating pain when they cohabitate with a spouse than when they live alone (as described in the next section below). In other words, experimental and clinical pain studies are mixed on whether males report heightened or dampened pain sensitivity in the presence of other women.

From a social signaling perspective, the biological fitness costs and benefits to men for demonstrating heightened or lessened vulnerability to females should theoretically be contingent on implicit social expectations and other factors such as the momentary level of debilitation (*i.e.*, degree of pain severity) of the pain-sufferer[8,9,11,25]. Females effectively serve as both an ecological and likely resource for consolation and caregiving for both sexes, as well as a potential reproductive partner for males. Since men tend to use empowerment gestures (*e.g.*, concealed pain behaviors) to attract prospective mating partners[88], whereas they use vulnerability gestures (*e.g.*, explicated pain behaviors) to elicit solicitous responses from more established and intimate social partners (*e.g.*, female-kin) in times of need (*i.e.*, when the individual is physically debilitated)[9], one would expect that the effect of women (hypoalgesic *vs* hyperalgesic) would depend on the relative state of debilitation (*e.g.*, degree of pain suffering) of the male.

We recently found evidence for these patterns, which we have come to refer to as the "Vigil-Alcock Effect"[89]. This is the tendency for males to report attenuated pain intensity in the presence of female observers, when at relatively low pain levels, but to experience heightened pain intensity in the presence of female observers, at high pain levels. Using multiple chart reviews we compared the patient pain scores that were taken during standard triage assessments for people who were admitted for emergency care by either a male or a female health provider (*e.g.*, nurse). We found that male patients reported higher pain intensity levels to male practitioners, when initial pain intensity is low (scores of 3 or below on a 10-point scale), and both male and female patients reported higher pain to female practitioners when initial pain intensity is high (scores greater than 4)[89]. The statistical magnitudes of these effects were substantially larger than those from typical, non-pharmacological (*e.g.*, psychological, placebo) clinical interventions, suggesting that the influence of this interaction between examiner gender and patient condition on patient pain reports may be a pervasive feature in clinical and experimental settings.

Interestingly, other research has found that the absolute number of males or females in the immediate audience also influences the observational coding of other people's pain suffering, irrespective of the sex of the pain sufferer and sex of the observer[6]. In general, greater numbers of male audience members correlated with lower observer pain ratings, whereas greater numbers of female audience members correlated with higher observer ratings. Thus, it would appear that people most broadly learn to simulate the prototypical appeasement styles of males and females, with females demonstrating greater compassion for others than males, on average. An alternative explanation is that, male and female observers' simulations of their own pain experiences influence their observational ratings of other people's pain suffering.

ENVIRONMENTAL VARIABILITY IN PAIN BEHAVIORS

A social-signaling perspective of pain predicts that people's close relationships should adaptively influence the phenotypic expression of exogenous (*e.g.*, experimental) and endogenous (*e.g.*, somatic) pain perception. Specifically, pain experiences should correspond to how often people interact with intimate (*e.g.*, in terms of shared time and interpersonal knowledge) relationship partners such as romantic partners, family, and close friends, and these associations should differ for males and females[6,8,9,10,27]. The inverse would also be true, that dampened pain sensitivity should co-occur with the frequency of interactions with less intimate and riskier affiliates[25]. An extension of this prediction is that the conventional finding of greater pain sensitivity in women[6,27,33,34,38] should be modulated, in part, by structural and functional components of the individual's social network[9]. In theory, the level of intimacy that individuals share with their network partners should compound biological sex differences in pain sensitivity, and thus the typical pattern of females reporting higher pain intensity than males should be the most robust for females that have a high proportion of intimate types of affiliates (*e.g.*, lover and relatives *vs* non-kin) and more established (*e.g.*, longer formed) relationships.

Indeed, numerous studies have shown that higher levels of pain-related social support and solicitous behaviors from significant relationship partners are associated with greater clinical pain experiences[90-94]. In a recent experiment, we also found consistent sex differences in how social network structures as well as intimate relationship functioning modulated experimental pain sensitivity[22]. Us-

ing a cold pressor task, we found that comparing males and females directly revealed no group differences in reported pain intensity. However, when structural and functional components of individuals' social networks were considered, inverse sex differences emerged, hence otherwise obscuring the dynamic relations between biological sex and exogenous pain sensitivity. Females who listed a greater proportion of intimate types of relationship partners (*i.e.*, kin or a significant other) among their list of most significant people and females with more extensive (*i.e.*, longer established) relationships reported higher pain intensity than males. Instead, males with fewer intimate and less established peer relationships actually reported higher pain intensity scores than females, on average. The most robust sex differences were moderated by the amount of logistical support received from one's significant other such that greater logistical support was associated with heightened pain intensity ratings in females, but with dampened pain intensity in males. This makes sense based on the hypothesis that males' natural tendencies to form less intimate peer relationships resulted in their slightly greater tendency to utilize empowerment gestures including pain tolerance behaviors (when at relatively low pain-levels) for regulating (*i.e.*, attracting and maintaining) their peer relationships. The female tendency to utilize vulnerability gestures including pain reaction behaviors for accomplishing similar goals[9,17,23,27] would then explain why women with more intimate relationships showed higher pain sensitivity than women with less intimate relationships.

As mentioned above, we have also found (unpublished data) that individuals, and particularly males, who reside with an intimate relationship partner such as a "significant other" (*e.g.*, boyfriend, girlfriend, spouse) are at greater risk for experiencing clinically debilitating pain interference than males with less intimate cohabitants and males who live alone. If females evolved a greater tendency than did males to regulate their relationships through trustworthiness demonstrations, including pain empathizing and related demonstrations of solicitude[9,17,23,27], it makes sense that the males who resided with a (presumed) female significant other were likely to have experienced heightened levels of pain reinforcement behaviors (when at relatively high pain-levels). Other research shows that the association between pain catastrophizing and clinical pain experiences is stronger for people who live with a romantic partner than for those who live with someone else[95]. Thus, while previous research has found that supportive (*e.g.*, functional) components of social networks are associated with health-related outcomes[11,96,97], there is building evidence that structural dimensions of social networks are also associated with distinct and potentially adaptive (*i.e.*, epigenetically specialized) expression of exogenous and endogenous pain sensitivity in males and females.

FUTURE DIRECTIONS FOR A SOCIAL-SIGNALING PERSPECTIVE OF PAIN

Collectively, the extant literature on the associations between social situational and social network dynamics and pain perception are interpretable from the social signaling thesis that there is a reciprocal relationship between changes in pain percepts and changes in the social environment. That is, not only do individuals' verbal and nonverbal pain behaviors evoke specialized and functional reactions-sometimes reinforcing and sometimes aversive-from other people, but individuals' current relationship dynamics and the social context influence pain perception[8,10-12,22]. This basic thesis can be used to construct more specific conceptual models that can guide the development of novel, evidence-based pain management treatment options.

One way that a social-signaling perspective can be useful is for providing a potential scaffold to better understand the current evolutionary and mechanistic paradoxes that characterize the discordant relations between affective functioning and pain perception. Emotion induction studies among healthy people, for instance, show that superficial (*e.g.*, non-salient, non-personal, and brief) sadness induction results in hyperalgesia to external or phasic (surface) skin painful stimuli, such as electrical, heat, and cold pressor pain[98-100]. Clinically depressed people, instead, show the opposite pattern, of dampened ability to detect and more tolerance of many forms of exogenous pain sensations compared to healthy controls[101,102]. These patterns are not always observed[103-105], however, and this may be due to variability in pain induction techniques across the studies; depression is associated with hyperalgesia to electrical and thermal pain, but with hyperaglesia to ischemic muscle pain, which may be more similar to pain caused by endogenous forces[106,107]. Thus, depression is associated with dampened ability to perceive exogenous pain, yet heightened experiences of daily deep tonic (*e.g.*, somatic) pain percepts[108-110]. Similar discordances characterize the literature pertaining to positive affect, such that superficial happiness induction results in hypoalgesia, whereas dispositional optimism and high trait self-esteem have been linked to hyperalgesia, despite the tendency for optimistic people to report fewer somatic pain complaints[109,110]. Currently, there are no conceptual models that can explain these seemingly antithetical observations, and conventional assumptions are that the discordances reflect a general dysregulation, or malfunctioning of a single (system-global) pain perception system. These suppositions can be re-interpreted from a social-signaling perspective.

We are developing and empirically testing a conceptual model for integrating and interpreting the complex relations between affective functioning and pain perception, which we refer to as a Divergent Affect Model of Pain Percepts (DAMPP). The main theses are that external and internal pain perception systems co-evolved for their distinct behavioral functions and the systems are differentially modulated by varying degrees, and divergent directions of changes in affect. From the perspective of the DAMPP, "positive" and "negative" affect ultimately facilitate broader behavioral strategies characterized by social novelty-seeking *vs* self-protection (as described

above), and external and internal pain percepts supplement these strategies in ways that are sometimes concordant (positively correlated) and other times discordant (inversely correlated). These patterns are systematic and may reflect logical correspondences between varying levels of affective functioning, different types of pain percepts, and systematic changes in the individual's social environment.

According to the SRFB[9,25], non-salient and hence shorter-lasting demonstrations of positive or negative affect (*e.g.*, momentary emotive gestures) as well as exogenous pain percepts evolved for manipulating the immediate situational context, for instance, by signaling important social information (*i.e.*, capacity cues and/or trustworthiness cues) to facultative audiences and, in the case of pain detection, for operating at a basic sensory level (for discriminating environmental stimuli) as described above. Salient and longer-lasting demonstrations of affect (*e.g.*, trait optimism, trait depression) and endogenous (*e.g.*, somatic) pain percepts represent more canalized behaviors that function instead for controlling one's broader social environment. If sustained elated mood behaviors ultimately operate to attract less familiar and hence riskier affiliates, and if sustained depressed mood operates to avert interactions with unfamiliar people and to strengthen relationships with intimate and trusted confidantes, then the degree and hence duration of changes in either positive or negative affect (from a baseline state) should correspond to increasingly homogeneous social environments characterized by a disproportionate number of either risky or reliable affiliates. Likewise, since endogenous pain percepts are less avoidable than pain caused by extrinsic forces, the lack of or heightened ability to sense endogenous pain discomfort may be more functional for instilling trait-like (honest-signaling) impressions of capacity versus trustworthiness cues to others than is possible *via* exogenous pain percepts; hence, the social signaling functions of endogenous pain are probably more similar to those of salient/sustained changes (rather than superficial/momentary changes) in affect[9,25]. In this sense, endogenous pain percepts are hypothesized to have evolved to regulate interactions with more distinct/sub-consciously chosen (risky *vs* reliable) types of social affiliates than did exogenous pain percepts and expedient affective gestures more generally.

According to the DAMPP, salient (environment-specific) states of positive *vs* negative affect are also accompanied by sustained changes (canalization) in basic sensory perceptual functioning in ways that may supplement social novelty-seeking and self-protection behavior strategies, respectively. Sustained positive affect should, in theory, co-occur with amplified global (system-wide) perceptual acuity for monitoring novel external stimuli in the environment (*e.g.*, visual, auditory, and tactile discrimination) and for potentiating interactions with riskier affiliates[9]. Sustained negative affect should instead correspond to dampened perceptual acuities (multi-sensory agnosia) that effectively hinder the ability to navigate novel environments, avert interactions with novel affiliates, and demonstrate phenotypic vulnerability and ultimately trustworthiness cues to intimate confidantes. This thesis explains why for instance positive mood is associated with a "broadening" of visual attention (*e.g.*, greater attention to peripheral stimuli and greater eye-gaze saccades[111], while low mood is instead associated with facultative decreases in one's visual field of view[112] as well as a decrease in attentional focus on global *vs* local visual information[113]. The current thesis is also consistent with fact that depression is associated with a general dampening of the ability to detect multiple forms of extrinsic information in the immediate environment including basic visual[114-118], auditory[119,120], olfactory[121-123], gustatory[124], and tactile stimuli[125].

Finally, the DAMPP model assumes that the continuous, environment-specific, and preparatory functions of sustained affect (*e.g.*, perceptual calibration) should take precedent and hence be expressed over the expedient, situation-specific functions of momentary affect (*e.g.*, social signaling). This is because the former phenotypes represents heuristical reactions to more specialized environmental circumstances which generally offset the biological benefits of being able to variably respond to environment (*i.e.*, phenotypic plasticity). Collectively, these lines of reasoning suggest that individual's current state of socio-relational functioning, which is characterized by distinct structural and functional characteristics of their social environment and by the expression of varying levels of affect and exogenous and endogenous pain percepts, can be used to interpret the paradoxical findings in the literature on the association between affective functioning and sensitivity to clinical and experimental pain. The DAMPP model explains that: at low levels of affective functioning (*e.g.*, momentary happiness *vs* sadness), endogenous pain percepts are not affected, and hence under these conditions exogenous pain percepts are free to operate, at the social-signaling level, for demonstrating expedient demonstrations of capacity *vs* trustworthiness cues to others.

This phenomena may partly account for the placebo effect and research showing that exposure to contextual factors that may superficially (*e.g.*, momentarily) alleviate or dampen mood modulate exogenous pain perception. For example, some research has found that coming in contact with ibuprofen (*vs* a neutral object) results in hypoalgesia and that exposure to words that signify an act of victimization such as "sting" as oppose to "beware" induces hyperalgesia[126,127]. Related studies show that people who are told that the exogenous pain they were exposed was the result of malicious intent by another person experience hyperalgesia[128,129], presumably as a result of the brief/situationally-relevant impact of the experimental manipulation on momentary affect.

In contrast, and under conditions in which the individual is experiencing significant and sustain changes in affect (*e.g.*, trait-confidence *vs* depression), the DAMPP model predicts that the social-signaling functions of

demonstrating continuous capacity or trustworthiness cues to selective social audiences are going to be accompanied by changes in endogenous pain perception. Indeed, empirical studies show that loss of material or social resources (diminished capacity attributes) is associated with heightened endogenous pain percepts such as menstrual discomfort[130]. Likewise, according to the DAMPP, continuous changes in positive and negative affect should be accompanied by a general heightening or dampening (respectively) of basic sensory acuity for navigating risky *vs* reliable environments. These changes in exogenous sensory acuities may be converse to sensory functioning when the individual is not experiencing salient mood states which, in theory, would have resulted in competing evolutionary selection pressures for expressing heightened external *vs* internal pain sensitivities under certain conditions.

This divergent affect model of internal *vs* external pain percepts appears to explain the empirical literature which shows discordant rates of internal (*i.e.*, somatic) and external (*i.e.*, experimental) pain sensitivities in people experiencing salient mood states, but not in healthy people who participate in conventional mood induction experiments. Additional factors such as individual differences in physical activity are also known to influence the relation between salient mood states such as depression and experimental pain thresholds[131] and clinical pain reports[132]. This makes sense from the DAMPP, which predicts that physical activity should partially mediate the relation between affective functioning and changes in exogenous and endogenous pain sensitivities in ways that facilitate broader behavioral strategies (novelty-seeking *vs* self-protection) characterized by differing mobility styles.

CONCLUSION

In summary, the social signaling perspective of pain-related behaviors provides a solid scaffold that can help clinicians and basic scientists predict how social situational and social environmental factors and how varying degrees of changes in affect may influence pain perception in the presence and absence of physical tissue-damage. The perspective is based on the general thesis that the human nervous system adaptively and systematically adjusts the heuristical expression of pain eliciting, pain concealing, and pain empathizing behaviors for manipulating interpersonal interactions and broader structural and functional components of the individual's social ecology. These heuristics appear to differ in males and females in specialized and functional ways that correspond to evolved sex differences in social relationship styles. Pain researchers may also choose to consider how the individual's current state of debilitation may modulate the influence of contextual factors (*e.g.*, audience characteristics) on pain percepts, and to consider how internal *vs* external pain sensitivities are related conceptually and mechanistically. There may be cost-benefit fitness tradeoffs associated with expressing discomfort that originates from either extrinsic or intrinsic forces that can be empirically tested with a better understanding of the experiential determinants and behavioral consequences of these different natural kinds of pain percepts. At the very least, pain researchers and health providers should recognize that characteristics of the individual's social environment influence how they report their pain, and that pain reports differ according to several factors, including interpersonal characteristics of the pain sufferer and the pain observer, interpersonal tradeoffs associated with expressing pain under varying debilitation-levels, to whether pain originates from controllable/avoidable (*e.g.*, exogenous, tissue-related) or uncontrollable/unavoidable (*e.g.*, endogenous, non-tissue dependent) forces.

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