

Social interaction and pain: An arctic expedition

Per Block^{a*}, Lauren C Heathcote^{b*}, Stephanie Burnett Heyes^{c*}

- a. Department of Humanities, Social and Political Science, ETH Zurich, Clausiusstrasse 50, 8092 Zürich, Switzerland
- b. Department of Anesthesiology, Perioperative, and Pain Medicine, Stanford University, 1070 Arastradero Road, Palo Alto, CA 94304, United States
- c. School of Psychology, University of Birmingham, B15 2TT, United Kingdom

* These authors contributed equally to this work

Corresponding author: Stephanie Burnett Heyes, School of Psychology, University of Birmingham; s.burnetttheyes@bham.ac.uk

Highlights

- Daily ratings of adolescent pain and social contact elicited during Arctic expedition
- Results show males in pain are nominated successively less as interaction partners
- Female network position is unaffected by pain experience
- No indication that interacting adolescents experience similar types of pain
- Innovative research design for study of network position and individual outcomes

Abstract

Complex human behaviour can only be understood within its social environment. However, disentangling the causal links between individual outcomes and social network position is empirically challenging. We present a research design in a closed real-world setting with high-resolution temporal data to understand this interplay within a fundamental human experience – physical pain. Study participants completed an isolated 3-week hiking expedition in the Arctic Circle during which they were subject to the same variation in environmental conditions and only interacted amongst themselves. Adolescents provided daily ratings of pain and social interaction partners. Using longitudinal network models, we analyze the interplay between social network position and the experience of pain. Specifically, we test whether experiencing pain is linked to decreasing popularity (increasing isolation), whether adolescents prefer to interact with others experiencing similar pain (homophily), and whether participants are increasingly likely to report similar pain as their interaction partners (contagion). We find that reporting pain is associated with decreasing popularity – interestingly, this effect holds for males only. Further exploratory analyses suggest this is at least partly driven by males withdrawing from contact with females when in pain, enhancing our understanding of pain and masculinity. Contrary to recent experimental and clinical studies, we found no evidence of pain homophily or contagion in the expedition group.

Keywords

Stochastic actor-oriented models, social networks, pain, adolescence, social influence, sex differences.

Introduction

Human traits, behaviors, and experiences are tightly linked to the structure of interpersonal interaction that spans social networks; neither one can be fully understood without reference to the other (Rivera, Soderstrom, & Uzzi, 2010). Accordingly, investigating the causal relationship between individual outcomes and embeddedness in social networks is an important, yet empirically difficult endeavour (Shalizi & Thomas, 2011). We present here a study design that explicitly and directly investigates longitudinal, bidirectional interactions between network position (the number and types of connected others) and a fundamental experience that drives much of human behaviour – physical pain.

Pain is a fundamental motivator of behaviour, serving to protect the body and ultimately promote lifespan. The study of pain in the psychosocial context appears especially interesting and promising, as the human experience of pain is now widely recognised to be situated within and shaped by the social world (Craig, 2009), making it a pertinent field for psychological enquiry. Past research on the association between pain and social relations has shown that higher pain tolerance is correlated with larger self-reported social group size (Johnson & Dunbar, 2016), and that chronic pain is linked to poorer relationships and self-imposed isolation (Smith & Osborn, 2007; Snelling, 1994). Experimentally-induced social exclusion and perceived social support respectively increase and reduce the severity of acute experimental pain (Brown, 2003; Eisenberger, Jarcho, Lieberman, & Naliboff, 2006; Master et al., 2009). Evidence suggests that, like depression (Schaefer et al., 2011), obesity (Cunningham et al., 2012), and numerous health-related behaviours (Steglich et al., 2010), pain may have the capacity to be socially transmitted (Martin et al., 2015). Also emerging is a role for sex, gender, and perceptions of masculinity/femininity, with these factors appearing to influence interactions between pain and social context (Keogh, 2006).

However, major questions remain. Current studies on the interactions between pain, sex, and social factors are limited, with most studies relying on reports from individual participants, dyadic interactions at single time-points, or experimentally induced pain. Little is known about reciprocal relations between naturally occurring pain and social networks over time. In this study, we analyse fine-grained, voluntary interactions between adolescents and their interdependence with naturally occurring pain in an observational study. Participants completing a 3-week hiking expedition in the Arctic Circle provided daily reports of interaction with others and ratings of pain. In this context, we focus specifically on (i) how the experience of pain is related to social integration and tie formation (pain popularity, pain homophily), and (ii) whether pain is “contagious”, that is, whether interacting with others in pain increases the likelihood of reporting similar pain experiences.

Pain and social integration

Empirical research suggests that chronic and recurrent pain in adults and adolescents negatively affects social relationships. For example, regularly experiencing pain is linked to having fewer friends, worse peer relationship quality, victimisation, and social problems within the family unit (see Forgeron et al., 2010 for a systematic review; Smith & Osborn, 2007; Forgeron et al. 2011, 2013; Lewandowski et al. 2007; Snelling 1994). Among the main mechanisms thought to underlie this relation in adolescents is the decreased likelihood of interacting with peers when in pain (Forgeron et al. 2010). Pain hinders the ability to take part in social activities and interactions as well as decreases the willingness to interact, with self-isolation being a negative coping mechanism for pain. At the same time, others might withdraw from interaction with adolescents in pain, as they are seen as less likable and less fun to spend time with (Forgeron et al. 2010).

However, the relation between experiencing acute pain and interaction frequency is likely to vary with sex (Keogh, 2006; Keogh, 2009; Keogh, 2012). Females and males tend to differ in their coping strategies for pain, with females being more likely to seek social support and share their experiences than males (Keogh, 2006; Bartley and Finnigan, 2013). Relatedly, cultural beliefs about masculinity and femininity influence the perception and social acceptability of expressing pain across gender (*ibid.*). For example, a recent study found sex differences in the encoding of pain-communicative body postures (Walsh, Eccleston, & Keogh, 2017). These perceptual differences, in turn, are likely to affect how males and females in pain are treated by others (Keogh, 2006). Another study found that males' pain tolerance increased only when in the presence of male, but not female, friends, which the authors speculate may be driven by cultural beliefs regarding competitiveness and the male prerogative to tolerate pain (Edwards, Eccleston, & Keogh, 2017; Walsh, Eccleston & Keogh, 2017). In the context of our study, this leads us to hypothesise that being in pain will lead to decreased interaction with other expedition participants. This relation should be especially strong for boys.

Social contagion of pain

Recent experimental evidence suggests that pain may have the capacity to be socially transmitted (Martin et al., 2015). In this experimental study, participants reported increased pain intensity when they observed a familiar other experiencing the same type of pain. The hypothesised mechanism for this finding is based on empathy. Empathy is the capability to understand the personal experience of another person, often coupled with affective responses (Goubert et al., 2005). In the context of empathy for pain, it has been shown that observing another person in pain elicits similar neuronal responses as if the observer were

experiencing this pain themselves (Singer et al., 2004), providing a neuronal basis for empathy.

Further, past research suggests that women tend to empathise more than men do (Han et al., 2008), and that women are more expressive of their pain (Walsh et al. 2017). In the context of our study, this leads us to hypothesise that interacting with a peer reporting a particular type of pain leads to a heightened probability of reporting the same type of pain. In light of previously found sex differences in empathy and pain communication, we believe this relation will be especially strong for girls.

As we elaborate in the next section, a common confounder in observational studies on social influence is homophily, the tendency of people to have ties to similar others. While we are not aware of studies that specifically analyse pain-homophily, similarity-attraction theory predicts that people seek out contact with others that have common experiences (McPherson et al. 2001). Similarity is presumed to lead to facilitation of communication and improved understanding of similar others. Homophily on distressing experiences has previously been analysed, for example, on negative affect (Schaefer et al. 2011) or victimisation from bullies (Lodder et al. 2015). Thus, we hypothesise that adolescents in our study tend to seek contact with others who experience similar levels and/or types of pain.

Research design

Research using observational data on the relation between pain and network position faces difficult empirical challenges, known from network studies in other domains (Christakis & Fowler, 2007; Cohen-Cole & Fletcher, 2008; Lyons, 2011). Disentangling cause and effect, that is whether network position predicts individual attributes or *vice versa*, is not trivial, as multiple psychosocial mechanisms can lead to the same cross-sectional outcome (Shalizi &

Thomas, 2011; Steglich, Snijders, & Pearson, 2010). Connected individuals suffering from similar types or intensity of pain could be a result of social transmission of pain (contagion), but also of selecting interaction partners that were already similar in the first place (homophily). Likewise, the association of social isolation and pain might be explained by ostracism of individuals in pain (decreasing popularity), as well as by social isolation leading to more intense pain experiences (Smith & Osborn, 2007). Additionally, unmeasured heterogeneous exogenous causes can lead to similar network patterns. In this case, common experiences lead, at the same time, to being socially connected and experiencing pain; for example, living in the same neighbourhood can lead to being socially connected as well as being subject to the same environmental stressors, such as pollution or noise.

Consequently, studies on the relation between networks and individual outcomes require longitudinal data in conjunction with multivariate statistical models that simultaneously model network evolution and changes in individual outcomes to distinguish cause and effect. Equally, tendencies of networks to evolve endogenously, such as reciprocity or clustering/transitivity need to be taken into account (Shalizi & Thomas, 2011; Steglich et al., 2010). At the same time, data collection should ensure that heterogeneous environmental influences are absent, i.e. that all study participants are exposed to the same exogenous factors that can influence the dependent variable.

We present here a study design that explicitly addresses these difficult requirements to investigate longitudinal, bidirectional interactions between pain and social network position, leveraging promising tools from social network analysis (Snijders, van de Bunt, & Steglich, 2010). Stochastic actor-oriented models (SAOMs) allow the simultaneous analysis of the evolution of networks, as well as change in actor attributes; for example, changes in social interactions in a group of individuals, changes in their experiences of pain, and the temporally

contingent relation of these observations. The SAOM continuous time approach enables disentangling of different network mechanisms that result in the same cross-sectional outcome: namely, selection versus influence.

In this study, we combine this method with temporally high-resolution data in an isolated but real-world setting. Late adolescents participating in a physically demanding, three-week hiking expedition in Greenland's Arctic Circle reported daily on their social interactions and pain experiences. Participants were exposed to the same environmental factors each day and interacted only with other members of the expedition group, allowing tight statistical control for potentially confounding heterogeneous influences. We analyze how reported pain and social connectedness are linked, and whether similarity of pain experienced by connected interaction partners is based on pain homophily or contagion.

We tested three hypotheses: 1) individuals report fewer interactions with peers who experience more pain (pain popularity); 2) individuals interact with peers who experience similar pain (pain homophily); 3) individuals become more similar to their peers in terms of pain (pain contagion). Given the moderating influence of sex on diverse pain experiences, we examined sex effects on each hypothesis.

Materials and Methods

Participants

Participants were recruited from an academically selective coeducational state secondary school in South East England. All participants had registered for a 3-week hiking expedition in the Arctic Circle, Greenland. The expedition was organized by the school, and students had registered for the expedition before they were contacted about taking part in the current

study. Nineteen participants from a single year group (grade level) had registered for the expedition and 17 (8 female; mean age 17 years) participated in the study. Participants reported being acquainted with network members for a mean duration of 5.86 (SEM 6.14) years, with range 0-17 years, before the start of the expedition. Participants gave informed consent to take part. Data were collected during July and August 2015. The study was approved by the University of Oxford Central University Research Ethics Committee.

Materials

Daily Pain Log. Each day participants reported their experience of seven different types of pain using a pain site checklist (Jensen, Hoffman & Cardenas, 2005): 1) Pain due to the cold, 2) Pain due to muscle use, 3) Headache, 4) Pain due to rubbing/blisters, 5) Pain from injuries, 6) Stomach ache, 7) Other pain. Pain types were chosen according to the general prevalence of pain (Moore *et al.*, 2013) as well as pain types judged to be especially relevant to the expedition. For each pain type the two main dimensions of pain, pain intensity and pain unpleasantness (Jensen & Karoly, 2011), were recorded on a numerical rating scale (NRS) from 0 to 10 (0 = no pain; 10 = worst possible pain and 0 = not at all unpleasant; 10 = extremely unpleasant). Validity of these measures is well documented (*ibid.*). Additionally, participants reported on pain frequency (0 = never; 10 = all day) for each type of pain. There was no missing data for the daily pain logs.

Daily Interactions Diary. Participants reported each day on their interactions with other members of the expedition team. These interactions reflect individuals' choices with whom to spend time. Participants were required to report the four persons with whom they spent the most time. Data were elicited using a questionnaire in which the number of nominated interaction partners is fixed, as the total time spent in the group, and thus the opportunity for interaction was constant across all participants. Participants also rated how enjoyable they

found each interaction (0 = extremely un-enjoyable; 5 = extremely enjoyable). Participants were instructed to only report on interactions with members of the team who were also participating in the study, therefore excluding the two students who did not take part, and the five adult expedition leaders. Two participants did not provide interaction data for one day each resulting in 0.6% missing data and 58 nominations were to expedition leaders or students not taking part, i.e. 4% invalid data recoded as missing.

Procedure

Participants woke between 7-8am each day and ate breakfast together. On most days they hiked for around 7 hours, arrived at a new campsite location around 4pm, ate dinner and rested. On two days during the expedition participants completed only a small hike and rested for the majority of the day. On the last two days participants were travelling back to a nearby city and resting; these days are excluded from inferential analysis. At the end of each day participants completed the Daily Pain Log and Daily Interactions Diary in private. As participants needed to carry their belongings on the hike each day, and had no access to the Internet, the measures were printed on A5 pieces of paper. Papers were combined into booklets and carried in waterproof document pouches. Each participant carried his/her own document pouch for the entire expedition.

Data analysis plan

Analysis proceeded via three steps: First, a general description of the networks; second, an analysis of descriptive statistics related to the outlined hypotheses; and third, statistical modelling of the data using SAOMs. In the descriptive analyses, the detailed pain ratings on the numerical rating scale were used. In the inferential analysis these measures were dichotomised, as outlined further in the relevant section. All analyses were conducted using the statistical software R. Network plots were created using the library “igraph”; SAOMs were

estimated with the library “RSiena” version 1.1-289 (Ripley et al. 2017). For both descriptive and inferential analyses, main results were obtained using daily reported pain intensity (analyses using pain unpleasantness and frequency are reported in the Supplementary Information). Further, only interactions rated as at least slightly enjoyable were included in the analysis, which comprised 98% of all measured interactions.

Descriptive Analysis

The descriptive analysis comprised of 1) visual inspection of the interaction networks, 2) scatter-plots assessing the relation between pain intensity and nominations received (separately for males and females), and 3) descriptive analysis of pain intensity homogeneity among network members. The first analysis is self-explanatory. For the second analysis, pain intensity for all measured pain variables was summed and plotted against the number of nominations received. We focus on the number of nominations received, i.e. popularity, to assess connectivity in this and all subsequent analyses, as the number of nominations sent is constant across all participants, due to our data collection strategy. The third analysis exploring pain homogeneity requires additional explanation, which is given below. For all descriptive analyses the use of standard tools to calculate confidence intervals was avoided, as the assumption of independent observations is violated for network data.

To descriptively assess similarity between interaction partners in terms of pain intensity, a network-based measure of pain homogeneity is proposed. This is defined as the sum of pain homogeneity of all connected pairs of individuals (in network research commonly denoted as actors) in the network. Pain homogeneity between two connected individuals is the sum of the minimum intensity of pain both interaction partners felt jointly for each type of pain. Formally, the network pain homogeneity h is defined as

$$h = \sum_{i,j} x_{ij} \sum_k \min(z_{i,k}, z_{j,k}),$$

where x_{ij} is the tie variable between actors i and j which equals 1 if they interact and 0 otherwise, k is the index running over all pain items, and $z_{i,k}$ is the amount of pain actor i felt on pain item k . As the network level score of h depends not only on pain homogeneity between actors, but also on overall pain intensity reported on a certain day and the specific network structure, the observed value of pain homogeneity was compared to a distribution of the expected value of pain homogeneity if individual pain experience were independent of the pain experience of interaction partners. This expected null distribution was calculated using permutations, leaving the network structure intact but randomly reassigning observed pain levels across individuals.

The Stochastic Actor-Oriented Model

Stochastic Actor-Oriented Models (SAOMs, Snijders et al., 2010) model the evolution of a network or the co-evolution of multiple networks and/or attributes of network actors over time. While data are recorded as panel data at discrete time-points, the model assumes changes happen in continuous time between the observations. Changes are modelled as a series of *mini-steps* comprising a change in a single tie variable or attribute of a single actor. Multiple *mini-steps* connect the observations at discrete time-points, while the exact ordering of the (unobserved) *mini-steps* is varied using simulations. The *mini-step* lies at the heart of the SAOM, as here hypotheses are tested by formalising them as parameters that influence how actors in the model chose their interaction partners or change their experience of pain. For further details of SAOMs, see (Snijders et al., 2010; Steglich et al., 2010).

In the reported model, technically the co-evolution of two networks over 18 consecutive periods is analysed (see Stadtfeld, Mascia, Pallotti, & Lomi, 2016). The first network depicts

the interactions between participants as outlined above. In the second network, participants technically form “ties” to different types of pain. A “tie” to a type of pain exists where the participant reports experiencing this pain equal to or more intensely than a threshold (in these analyses a threshold of 2 was used for the pain scales; robustness to other thresholds is checked). This transformed projection of data is called a bipartite network. While dichotomising the pain variables results in some loss of information, modelling pain as a bipartite network is much closer to our theoretical argument outlined in the introduction, as elaborated below.

In the model in each *mini-step* an actor can, when it comes to changing the pain experiences, create a new “tie”, i.e. report a new type of pain, or delete an existing “tie”, i.e. report that a pain previously experienced is now absent. These changes in reporting pain depend, among others, on whether their interaction partners have a “tie” to this type of pain. Thus, it allows modelling whether the actors start feeling the same type of pain that their friends feel, that is, influence in pain experience (contagion hypothesis).

At the same time, if actors changes ties in the interaction network, they can stop or start to interact with any other actor in the network. This depends, among other factors, on how many types of pain the potential interaction partner reports and how many pain types ego and alter share. These statistics relate to the hypothesis on pain popularity and on pain homophily, respectively.

The strength of using the bipartite network is of theoretical and technical nature – empathy is assumed to work on the same dimension of pain. Interacting with someone that has a headache is proposed to influence the probability to report a headache, but not another type of pain, such as pain from cold. At the same time, coding all pain intensity variables into one bipartite network increases the statistical power, as it allows estimating one overall

influence parameter (and homophily / popularity parameter) rather than an influence parameter for each type of pain, or an influence parameter on one overall pain measure.

Technically, influence is modelled as the closure of a triangle when actor i starts to report pain item k if the connected interaction partner actor j reports pain item k . The tendency of girls to be differentially influenced by peer pain is modelled by an interaction of the above-mentioned parameter and the sex of the focal actor i . Pain popularity is modelled as forming a relation from actor i to actor j , based on the number of pain items k actor j reports. Pain homophily is modelled as actor i forming a tie to actor j based on the number of pain item k both have in common. The differential effect of pain on popularity in boys and girls is modelled by an interaction between the mentioned parameter and the sex of the receiving actor j .

In both the pain and network evolution parts of the model a number of control parameters were included. For pain evolution, it is modelled whether girls tend to report more pain types than boys, and whether some individuals show an inherent tendency to report more pain (outdegree Activity). Further, the propensity to experience different types of pain is modelled using dummy variables for each type of pain (with pain from cold as the arbitrary reference category); 18 additional dummy variables are included for each day of the hike to control for differential strenuousness of each day. For network evolution, the tendency of interactions to be mutual and to cluster in groups, as well as their statistical interaction, i.e. testing whether mutuality is more or less prevalent in social groups, is modelled as a control. Further, sex differences in popularity and sex homophily (that is, a preference to interact with same-sex peers) are included in the analysis.

For further explanation of the SAOM and details of the estimation routine and algorithms, see Supplementary Information.

Results

Initial description of the data shows that the network tends to be relatively stable over the course of the expedition, with an average turn-over of one third of the ties each day. The experience of pain had large variation within, as well as between, individuals. There was large variation in intensity across different types of pain (see Supplementary Information).

Descriptive Analysis

Figure 1 shows the social interaction network at four time-points five days apart, with each individual's intensity and type of pain. The plots show that some adolescents tend to be in more pain over the entire course of the expedition, e.g. the two nodes towards the lower right of the network are larger and deeper red than the average node. However, it is difficult to discern from visual inspection alone whether adolescents in pain are relatively less connected, or whether connected adolescents tend to report similar levels of pain.

Descriptive statistics related to the hypotheses explore (i) the relation between experiencing pain and being nominated as an interaction partner for males and females, and (ii) the amount of homogeneity in pain experience between interaction partners for males and females. Figure 2 shows a scatterplot representing the relationship between experiencing pain and being nominated as an interaction partner, separately for males and females (popularity hypothesis). The popularity of females seems unaffected by the amount (intensity) of pain they report. For males, this was not the case; the more pain males experienced, the fewer nominations they received.

Figure 3 visualises whether connected pairs of participants experienced similar levels and types of pain, compared to a null-distribution created under the assumption that network position and pain experience are independent. This is related to the hypotheses on pain homophily and contagion, both of which should result in connected adolescents being more similar than random pairs in the network. The grey shaded area shows the 50% and 90% confidence band of expected observations were pain and interaction independent, with changes in the null distribution across days resulting from differences in pain experiences over the course of the expedition (see SI); the red line shows the empirically observed value. The plots suggest there is no systematic deviation from the null-distribution. Additional analyses (see Figure S2 in the SI) show that pain homogeneity equally does not exceed the expectation under the null hypothesis when looking only at same sex interaction pairs. Hence, there is no descriptive evidence that either pain homophily or pain contagion are present in the data – neither for males, nor for females, nor for the entire network.

Statistical Analysis using SAOMs

The results of the analysis using SAOMs reveal tendencies according to which individuals change their social interactions and individual attributes. Since both types of changes are modelled simultaneously in continuous time, SAOMs permit dissociation of selection from influence processes. Using SAOMs, hypotheses outlined in the introduction regarding pain popularity and pain homophily were tested by including them as terms in the network evolution part of the model that represent whether participants tended to report being more or less connected to others who are in more pain, or who experienced similar amounts of pain, respectively. The third hypothesis (pain contagion) was tested in the pain evolution part, modelling whether adolescents tend to experience specific types of pain if their interaction

partners do so.

Table 1 shows the results of the SAOM analyses. Three models were estimated. In the first model, the effects related to the basic hypotheses (pain popularity, pain homophily, and pain contagion) are included. The second model analyses whether there are differences in pain popularity and pain contagion between males and females. The third and final model is exploratory in nature and further analyses the patterns found in the previous models that relate to a decreased popularity of males in pain. Model 1 shows no evidence that adolescents nominate as interaction partners others that report similar types of pain, as the Pain Homophily parameter is small and the confidence interval includes zero. At the same time, there is no evidence that interacting with others who report certain types of pain leads to participants reporting more of the same type of pain, as shown in the small and non-significant Pain Contagion estimates. Thus, we find no evidence that support the hypotheses on pain homophily or pain contagion, in line with the descriptive analyses in the previous section. However, we see that adolescents who report more types of pain are less popular as interaction partners, as the negative, significant Pain Popularity parameter shows. This supports the hypothesis on pain popularity.

As the descriptive statistics in Figure 2 suggest, this decreased popularity might not hold equally for males and females, which is tested in Model 2. Indeed, the interaction Pain Popularity * Male is negative and significant. At the same time, the size of the main effect diminishes and becomes non-significant. Thus, males in pain are less attractive as interaction partners, while there is no effect for females. Model 2 further analyses whether the pain contagion parameter might differ between males and females. However, the included Pain Contagion * Female interaction is comparably small and non-significant. Thus, we find no

evidence for pain contagion, neither between all connected peers, nor between peers of the same sex.

Finally, Model 3 explores the relationship between nomination patterns and sex beyond our initial hypotheses. The questions explored are whether males in pain are unpopular especially among males (parameter Males Nominate Males in Pain) and whether males in pain change their levels of interaction with females (parameter Males in Pain Nominate Females). While the former interaction is statistically not distinguishable from zero, males in pain seem to withdraw from interactions with females, as the significant negative parameter suggests. Additional descriptive analyses confirm this finding, as shown in Figure 4. Males who report more pain nominate considerably fewer female interaction partners.

The further model parameters give interesting insights into the evolution of the interaction network over time, as well as predictors of pain experience. Nomination of interaction partners generally tends to be mutual (Reciprocity), between adolescents of the Same Sex, and embedded in a mutual interaction with a third participant (Transitivity). The exact operationalization of transitivity takes the form of *geometrically weighted edgewise shared partners* (GWESP), meaning that there are decreasing returns of an interaction tie to be embedded in multiple triangles. As elaborated in the literature (Block, 2015), the negative Reciprocity * Transitivity interaction indicates that the importance of reciprocity is higher outside than within groups. Finally, there is no large dispersion in the number of nominations received, as indicated by the negative Indegree Popularity parameter. The model related to the pain evolution shows that females are more likely to report being in pain than males (Effect from Sex). Further, there is a strong spread in how much pain individuals report (Outdegree Activity). Finally, different types of pain have different probabilities to be experienced as shown in the six dummy effects for the different pain types. An additional 36

rate-variables modelling the amount of change of the network and changes in pain were included, as well as 18 fixed effects modelling the strenuousness of each hiking day, to control for potentially confounding environmental effects across time, not shown in Table 1.

Additional analyses were conducted using the overall level of pain intensity participants experienced, as well as analyses using pain unpleasantness and frequency to construct the dependent variable; all of which led to the same findings (see Supplementary Material). Further models testing whether social exclusion causes stronger pain experience, i.e. the causal inverse to the pain popularity hypothesis, found no substantive results.

Discussion

We investigated the dynamic interplay between pain and social interactions, addressing previous methodological difficulties by using longitudinal, temporally high resolution data elicited in an isolated, real-world setting and analysed using stochastic actor-oriented models (SAOMs). By doing so we disentangle pain-related popularity, homophily, and contagion, and their interaction with sex for our sample of 17 adolescents participating in an expedition in extreme environmental conditions. Results show no evidence of pain homophily or pain contagion. We found that participants – specifically, males – who reported more pain received successively fewer nominations as interaction partners, while also nominating fewer females. The network position of females, in contrast, was unaffected by their pain experiences.

Our finding that increased pain can be detrimental for social interactions is consistent with previous findings in clinical samples (Forgeron et al., 2010; Smith & Osborn, 2007; Snelling, 1994), as well as evidence that pain experiences can impede peer interactions in adolescence

specifically (Forgeron et al., 2010). Indeed, during adolescence, peer relationships become critically important as time spent with family members diminishes (De Lorme, Bell, & Sisk, 2013; Nelson, Leibenluft, McClure, & Pine, 2005). However, few studies investigate the moderating role of sex in the interplay between pain and peer interactions in youth. Our study adds to this new area of research suggesting that peer interactions may be differentially affected for adolescent males and females in pain. Given that pain is common in childhood, with around 25% of young people experiencing chronic or recurrent pain (Perquin et al., 2000), and a significant minority experiencing severe, disabling, and distressing pain (King et al., 2011), a greater understanding of the individual and social factors associated with pain in youth is a pressing issue.

The findings in our sample of decreased popularity of males, but not females, reporting pain is consistent with existing evidence that sex and gender play important roles in pain and pain behavior (Bartley & Fillingim, 2013; Keogh, 2006). Specifically, male sex is typically associated with reporting less pain in experimental and clinical studies (Bartley & Fillingim, 2013; Keogh, 2006), which might be at least partially explained by gender role expectations, with masculinity being linked to a stoic characteristic, whereas femininity is perceived as more sensitive (Keogh, 2009). While the literature on sex differences in pain has been rather separate from studies on social experiences in clinical populations, the current study examines sex differences within the broader social context. Of particular relevance to understand our findings is the literature on masculinity and pain, which suggests that poor health, including increased pain, can be perceived as a threat to masculinity (Keogh, 2006). Recent experimental evidence indeed supports that males are more likely to tolerate pain when in the presence of a male, but not female, friend (Boerner, Eccleston, & Keogh, 2017). Evidence of experiencing pain may thus be less appealing in a male social partner, leading to

receiving fewer nominations. The finding that males in pain nominated fewer females as interaction partners equally points towards pain threatening masculinity. This signposts hypotheses to test regarding psychological correlates of observed inter-individual effects. However, other explanations for the decreased popularity of males are possible. As outlined in the introduction, different coping strategies by sex could explain the found sex differences. For example, experimental studies in healthy adults have found that, in the short term, focusing on pain may be of benefit to men but not to women (see Keogh, 2006), and thus males might focus more on the pain and on themselves when in pain, leading to less intense social contact. Regarding the observed lack of impact of pain on and by female social interactions, there is also speculation that female peers may be more likely to focus on and prioritise social support and intimacy, and thus be less inhibited to express signals associated with pain (Reis, Senchak, & Solomon, 1985; Edwards, Eccleston, & Keogh, 2017).

Our research design addresses a number of difficult methodological issues in disentangling individual from social factors, and may provide a frame for investigating other topics where similar issues arise. The role of social interactions during group-based inpatient rehabilitation programs for chronic pain invites a similar design. In different domains, influence processes in, e.g., affect or health-related behaviors, could be analyzed in isolated groups, such as hiking expeditions. Combining such data with SAOMs promises to gain detailed insight into processes of social selection and social influence in bounded networks, especially given that numerous studies claim to have found social influence on diverse outcomes such as smoking, drinking, depression, obesity, cultural consumption, and even loneliness. However, control of environmental influences in these studies is often necessarily limited, largely due to individuals' embedding in larger communities and data collection occurring several months or years apart. In this light, our null findings regarding effects of pain homophily and contagion

are themselves interesting. This is especially true given that studies of pain contagion have only recently started emerging, but came to other conclusions (Martin et al., 2015), indicating that these effects may only emerge under certain conditions. Our approach also provides an excellent setting for examining fluctuations in naturally occurring pain. An expedition in the Arctic Circle is both physically strenuous and subject to extreme fluctuations in the natural elements, generating pain in expedition participants that is varied in type and intensity.

The current study has limitations. First, whilst sex differences were a focus of the current study, gender may also be relevant, especially given the plausible role of masculinity in partly explaining our effects (Keogh, 2006). Future studies should measure self-identified gender roles and perceptions of masculinity and femininity as well as sex. Second, our participant sample is small ($N=17$), limiting generalizability to a wider population. However, the observation sample is of considerable size with each participant rating 7 pain items and nominating 4 contacts over 21 days, resulting in substantial statistical power. For the purpose of this article, the limitations of a small participant sample are secondary to the benefits of obtaining intricate longitudinal data within a tightly-controlled environment. Nevertheless, the experience of previously acquainted, healthy, late adolescents in an extreme environment might not generalize to other populations. Our findings on popularity may apply particularly to evolving interactions between acquainted individuals. Third, the current measures do not fully enable us to disentangle whether the causes of reduced popularity of males in pain are active 'social rejection' or self-imposed 'withdrawal'. The latter explanation would suggest that males who report more pain withdraw from social interactions, perhaps because their increased pain leads to low mood, or threat to male identity (Jackson, Iezzi, Chen, Ebnet, & Eglitis, 2005). This could make them less inclined to seek social interaction (with females), which, in turn, would result in fewer received nominations. Further studies combining social

network methods with the study of intra-individual psychological mechanisms are needed to shed light on these outstanding questions.

In sum, our study demonstrates that it is possible to overcome common problems with research on the interaction between individual and social processes, and provides rigorous insight into the relation of acute pain and social interaction.

Acknowledgments

PB is funded by an ETH fellowship. LCH is funded by an Action Medical Research for Children Research Training Fellowship (Grant Reference: GN2122). SBH was funded by a British Academy Postdoctoral Research Fellowship. We are tremendously grateful to Maia Sherwood-Rogers who presented us with this research opportunity and coordinated data collection. We thank Poppy Brown and Alexander Temple McCune for their assistance with data entry, and Christoph Stadtfeld, Ian Apperly, and Sarah Beck for critical reviews of earlier versions of the manuscript.

References

- Bartley, E. J., & Fillingim, R. B. (2013). Sex differences in pain: A brief review of clinical and experimental findings. *British Journal of Anaesthesia*.
<https://doi.org/10.1093/bja/aet127>
- Block, P. (2015). Reciprocity, transitivity, and the mysterious three-cycle. *Social Networks*, 40, 163–173. <https://doi.org/10.1016/j.socnet.2014.10.005>
- Brown, J. L. (2003). Social Support and Experimental Pain. *Psychosomatic Medicine*, 65(2), 276–283. <https://doi.org/10.1097/01.PSY.0000030388.62434.46>
- Christakis, N. a, & Fowler, J. H. (2007). The spread of obesity in a large social network over 32 years. *The New England Journal of Medicine*, 357(4), 370–9.
<https://doi.org/10.1056/NEJMs066082>
- Cohen-Cole, E., & Fletcher, J. M. (2008). Detecting implausible social network effects in acne, height, and headaches: longitudinal analysis. *Bmj*, 337, a2533–a2533.
<https://doi.org/10.1136/bmj.a2533>
- Craig, K. D. (2009). The Social Communication Model of Pain. *Canadian Psychology*, 50(1), 22–32. <https://doi.org/10.1037/a0014772>
- Cunningham, S. A., Vaquera, E., Maturo, C. C., & Narayan, K. V. (2012). Is there evidence that friends influence body weight? A systematic review of empirical research. *Social science & medicine*, 75(7), 1175-1183.
- De Lorme, K., Bell, M. R., & Sisk, C. L. (2013). The Teenage Brain: Social Reorientation and the Adolescent Brain--The Role of Gonadal Hormones in the Male Syrian Hamster. *Current Directions in Psychological Science*, 22(2), 128–133.
<https://doi.org/10.1177/0963721413479607>
- Edwards, R., Eccleston, C. and Keogh, E., (2017). Observer influences on pain: an experimental series examining same-sex and opposite-sex friends, strangers, and romantic partners. *Pain*, 158 (5), 846-855.

- Eisenberger, N. I., Jarcho, J. M., Lieberman, M. D., & Naliboff, B. D. (2006). An experimental study of shared sensitivity to physical pain and social rejection. *Pain*, 126(1–3), 132–138. <https://doi.org/10.1016/j.pain.2006.06.024>
- Forgeron, P. A., King, S., Stinson, J. N., McGrath, P. J., MacDonald, A. J., & Chambers, C. T. (2010). Social functioning and peer relationships in children and adolescents with chronic pain: A systematic review. *Pain Research & Management*, 15(1), 27–41.
- Forgeron P. A., McGrath P., Stevens B., Evans J., Dick B., Finley G. A., & Carlson T. (2011). Social information processing in adolescents with chronic pain: My friends don't really understand me. *Pain*, 152, 2773–2780.
- Forgeron P. A., Evans J., McGrath P. J., Stevens B., & Finley G. A. (2013). Living with difference: exploring the social self of adolescents with chronic pain. *Pain Res. Manag.* 18 e115-123.
- Goubert, L., Craig, K. D., Vervoort, T., Morley, S., Sullivan, M. J. L., de CAC, W., ... & Crombez, G. (2005). Facing others in pain: the effects of empathy. *Pain*, 118(3), 285-288.
- Jackson, T., Iezzi, T., Chen, H., Ebnet, S., & Eglitis, K. (2005). Gender, interpersonal transactions, and the perception of pain: An experimental analysis. *Journal of Pain*, 6(4), 228–236. <https://doi.org/10.1016/j.jpain.2004.12.004>
- Johnson, K. V.-A., & Dunbar, R. I. M. (2016). Pain tolerance predicts human social network size. *Scientific Reports*, 6(April), 25267. <https://doi.org/10.1038/srep25267>
- Jensen, M. P., Hoffman, A. J., & Cardenas, D. D. (2005). Chronic pain in individuals with spinal cord injury: a survey and longitudinal study. *Spinal cord*, 43(12), 704-712.
- Jensen, M. P. & Karoly, P. (2011). Self-Report Scales and Procedures for Assessing Pain in Adults. In Turk, D. C. & Melzack, R. (Eds.) *Handbook of Pain Assessment*. New York: The Guilford Press.
- Keogh, E. (2006). Sex and gender differences in pain: a selective review of biological and psychosocial factors. *The Journal of Men's Health & Gender*, 3(3), 236–243.

<https://doi.org/10.1016/j.jmhg.2006.03.006>

Keogh, E. (2009). Sex differences in pain. In: Moore, R. J., ed. *Biobehavioral Approaches to Pain*. New York, U. S. A.: Springer, 125-148.

Keogh, E. (2012). Sex differences in pain across the life course. In: Moore, R., ed. *Handbook of Pain and Palliative Care*. Springer, 347-366.

King, S., Chambers, C. T., Huguet, A., MacNevin, R. C., McGrath, P. J., Parker, L., & MacDonald, A. J. (2011). The epidemiology of chronic pain in children and adolescents revisited: A systematic review. *Pain*, 152(12), 2729–2738.

<https://doi.org/10.1016/j.pain.2011.07.016>

Lewandowski, W., Morris, R., Draucker, C. B., & Risko, J. (2007). Chronic pain and the family: Theory-driven treatment approaches. *Issues in Mental Health Nursing*, 28(9), 1019-1044.

Lodder, G. M., Scholte, R. H., Cillessen, A. H., & Giletta, M. (2016). Bully victimization: selection and influence within adolescent friendship networks and cliques. *Journal of youth and adolescence*, 45(1), 132-144.

Lyons, R. (2011). The Spread of Evidence-Poor Medicine via Flawed Social-Network Analysis. *Statistics, Politics and Policy*, 2(1), 1–26. <https://doi.org/10.2202/2151-7509.1024>

Martin, L. J., Hathaway, G., Isbester, K., Mirali, S., Acland, E. L., Niederstrasser, N., ... Mogil, J. S. (2015). Reducing social stress elicits emotional contagion of pain in mouse and human strangers. *Current Biology*, 25(3), 326–332.

<https://doi.org/10.1016/j.cub.2014.11.028>

Master, S. L., Eisenberger, N. I., Taylor, S. E., Naliboff, B. D., Shirinyan, D., & Lieberman, M. D. (2009). A picture's worth: Partner photographs reduce experimentally induced pain. *Psychological Science*, 20(11), 1316–1318. <https://doi.org/10.1111/j.1467-9280.2009.02444.x>

McPherson, M., Smith-Lovin, L., & Cook, J. M. (2001). Birds of a feather: Homophily in social

- networks. *Annual review of sociology*, 27(1), 415-444.
- Moore, D. J., Keogh, E., Crombez, G., & Eccleston, C. (2013). Methods for studying naturally occurring human pain and their analogues. *Pain*, 154(2), 190-199.
- Nelson, E. E., Leibenluft, E., McClure, E. B., & Pine, D. S. (2005). The social re-orientation of adolescence: a neuroscience perspective on the process and its relation to psychopathology. *Psychological Medicine*, 35, 163–174.
<https://doi.org/10.1017/S0033291704003915>
- Perquin, C. W., Hazebroek-Kampschreur, A. a J. M., Hunfeld, J. a M., Bohnen, A. M., Van Suijlekom-Smit, L. W. a, Passchier, J., & Van Der Wouden, J. C. (2000). Pain in children and adolescents: A common experience. *Pain*, 87(1), 51–58.
[https://doi.org/10.1016/S0304-3959\(00\)00269-4](https://doi.org/10.1016/S0304-3959(00)00269-4)
- Reis H. T., Senchak M., & Solomon B. (1985). Sex differences in the intimacy of social interaction: further examination of potential explanations. *J Pers Soc Psychol* 48, 1204–1217.
- Ripley, R. M., Snijders, T. A. B., Boda, Z., Vörös, A., & Preciado, P. (2017). *Manual for RSiena*. Oxford: University of Oxford, Department of Statistics; Nuffield College.
- Rivera, M. T., Soderstrom, S. B., & Uzzi, B. (2010). Dynamics of dyads in social networks: Assortative, relational, and proximity mechanisms. *Annual Review of Sociology*, 36(1), 91–115. <https://doi.org/10.1146/annurev.soc.34.040507.134743>
- Schaefer, D. R., Kornienko, O., & Fox, A. M. (2011). Misery does not love company: Network selection mechanisms and depression homophily. *American Sociological Review*, 76(5), 764-785.
- Shalizi, C. R., & Thomas, A. C. (2011). Homophily and Contagion Are Generically Confounded in Observational Social Network Studies. *Sociological Methods & Research*, 40(2), 211–239. <https://doi.org/10.1177/0049124111404820>
- Singer, T., Seymour, B., O'doherty, J., Kaube, H., Dolan, R. J., & Frith, C. D. (2004). Empathy

for pain involves the affective but not sensory components of pain. *Science*, 303(5661), 1157-1162.

Smith, J. A., & Osborn, M. (2007). Pain as an assault on the self: An interpretative phenomenological analysis of the psychological impact of chronic benign low back pain. *Psychology & Health*, 22(5), 517–534. <https://doi.org/10.1080/14768320600941756>

Snelling, J. (1994). The effect of chronic pain on the family unit. *Journal of Advanced Nursing*, 19(3), 543–551. <https://doi.org/10.1111/j.1365-2648.1994.tb01119.x>

Snijders, T. A. B., van de Bunt, G. G., & Steglich, C. E. G. (2010). Introduction to stochastic actor-based models for network dynamics. *Social Networks*, 32(1), 44–60. <https://doi.org/10.1016/j.socnet.2009.02.004>

Stadtfeld, C., Mascia, D., Pallotti, F., & Lomi, A. (2016). Assimilation and differentiation: A multilevel perspective on organizational and network change. *Social Networks*, 44, 363–374. <https://doi.org/10.1016/j.socnet.2015.04.010>

Steglich, C., Snijders, T. A. B., & Pearson, M. (2010). Dynamic Networks And Behavior: Separating Selection From Influence. *Sociological Methodology*, 40(1), 329–393. <https://doi.org/10.1111/j.1467-9531.2010.01225.x>

Walsh, J., Eccleston, C. and Keogh, E. (2017). Sex differences in the decoding of pain-communicative body postures. *European Journal of Pain*. Forthcoming.

Figure Captions

Figure 1: The interactions network at four time points

Arrows between nodes indicate directed nominations as interaction partners; Node layout includes information on different types of pain: Node size: Intensity of pain from muscle use (larger = more pain); Node color: Intensity of pain from cold (deeper red = more pain); Node shape: Intensity of pain from blisters (square = pain intensity > 3); Node frame: Intensity of other pain (deeper red = more pain).

Figure 2: Nominations received by total amount of pain experienced

Popularity of participants dependent on the overall amount of pain experienced in one day, measured by number of received nominations. Each participant is represented by 21 data points, once for each day.

Figure 3: Pain homogeneity by day

The black dotted line shows the mean expected homogeneity of pain between connected participants, the dark grey area and the light grey area the 50% and 90% bands of expected homogeneity. The red solid line shows the observed amount of pain homogeneity.

Figure 4: Cross-sex nominations by total amount of pain experienced

Number of cross-sex nominations by participants dependent on overall pain. Each participant is represented by 21 data points, once for each day.

Tables

Table 1: Results of the SAOM analysis for the co-evolution of the interaction network and pain

Network Evolution	Model 1			Model 2			Model 3		
	estimate	sig	s.e.	estimate	sig	s.e.	estimate	sig	s.e.
Outdegree (Intercept)	-2.110	***	(0.193)	-2.092	***	(0.197)	-2.193	***	(0.206)
Reciprocity	2.587	***	(0.208)	2.608	***	(0.206)	2.618	***	(0.211)
Transitivity (GWESP)	1.587	***	(0.103)	1.590	***	(0.106)	1.591	***	(0.105)
Indegree Popularity	-0.142	***	(0.032)	-0.175	***	(0.035)	-0.171	***	(0.035)
Reciprocity * Transitivity (GWESP)	-1.458	***	(0.192)	-1.478	***	(0.190)	-1.495	***	(0.192)
Sex Popularity (Girl)	0.062		(0.077)	0.187	*	(0.089)	0.111		(0.094)
Same Sex	0.369	***	(0.070)	0.380	***	(0.070)	0.467	***	(0.098)
Pain Popularity	-0.257	***	(0.072)	-0.095		(0.087)	-0.136		(0.089)
Pain Homophily	0.078		(0.062)	0.068		(0.063)	0.134		(0.070)
Pain Popularity * Male				-0.398	**	(0.131)	-0.405	*	(0.161)
Males Nominate Males in Pain							0.038		(0.148)
Males in Pain Nominate Females							-0.300	*	(0.141)
Pain Evolution									
Intercept	-2.167	***	(0.172)	-2.223	***	(0.213)	-2.182	***	(0.176)
Outdegree Activity	0.242	***	(0.027)	0.243	***	(0.027)	0.244	***	(0.026)
Effects from Sex	0.431	**	(0.135)	0.517	*	(0.234)	0.431	**	(0.134)
Pain Influence	-0.076		(0.102)	-0.034		(0.143)	-0.077		(0.105)
Influence * Females				-0.083		(0.189)			
Muscle Use (ref: cold)	0.772	***	(0.222)	0.765	***	(0.220)	0.781	***	(0.221)
Headache	-2.045	***	(0.359)	-2.059	***	(0.365)	-2.046	***	(0.358)
Rubbing and Blisters	0.267		(0.217)	0.263		(0.219)	0.273		(0.216)
Injuries	-0.377		(0.231)	-0.384		(0.228)	-0.374		(0.228)
Stomach ache	-0.858	***	(0.252)	-0.862	***	(0.254)	-0.863	***	(0.250)
Other Pain	-0.898	***	(0.259)	-0.897	***	(0.261)	-0.889	***	(0.260)

Levels of significance and p-values: *** <0.001; ** <0.01; * <0.05; Rate parameters for network evolution and dummies for each day omitted. Results using pain from cold as the reference category is an arbitrary choice.

Figures

Figure 1

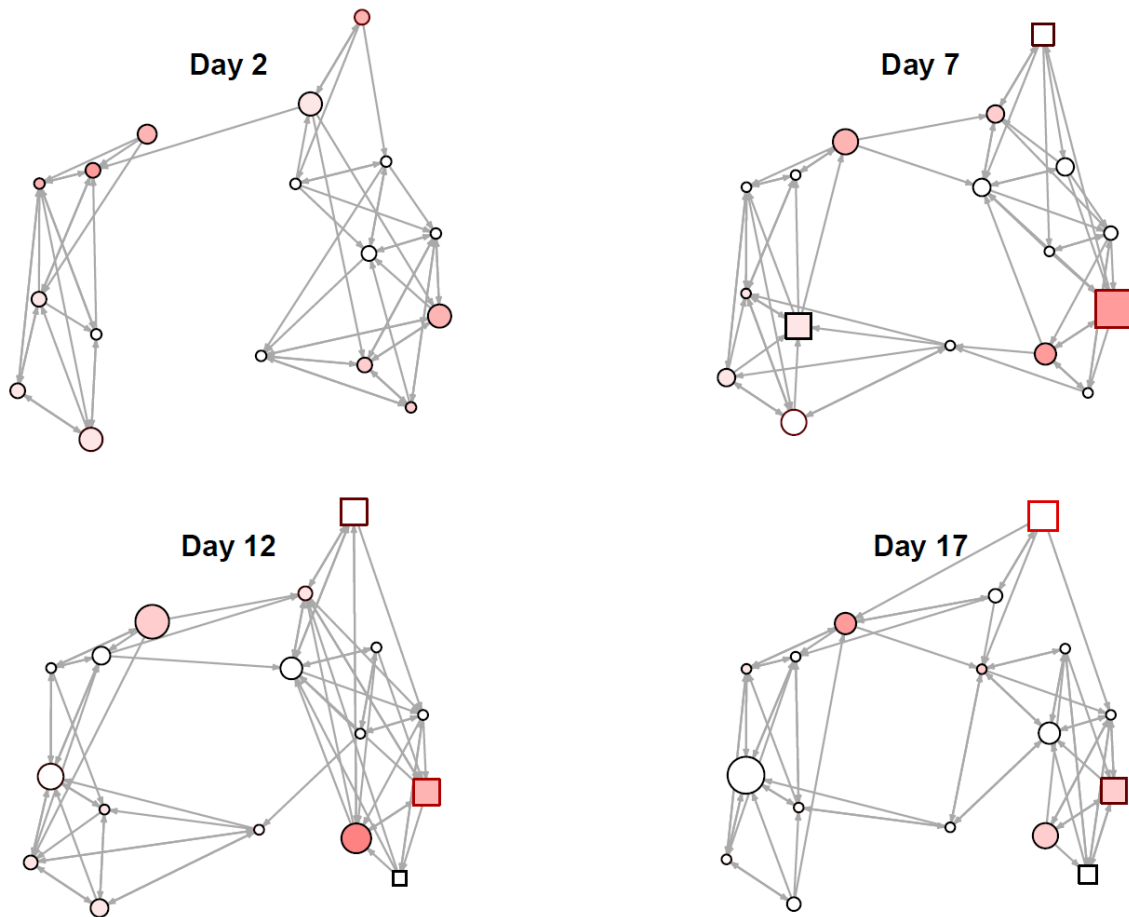


Figure 2

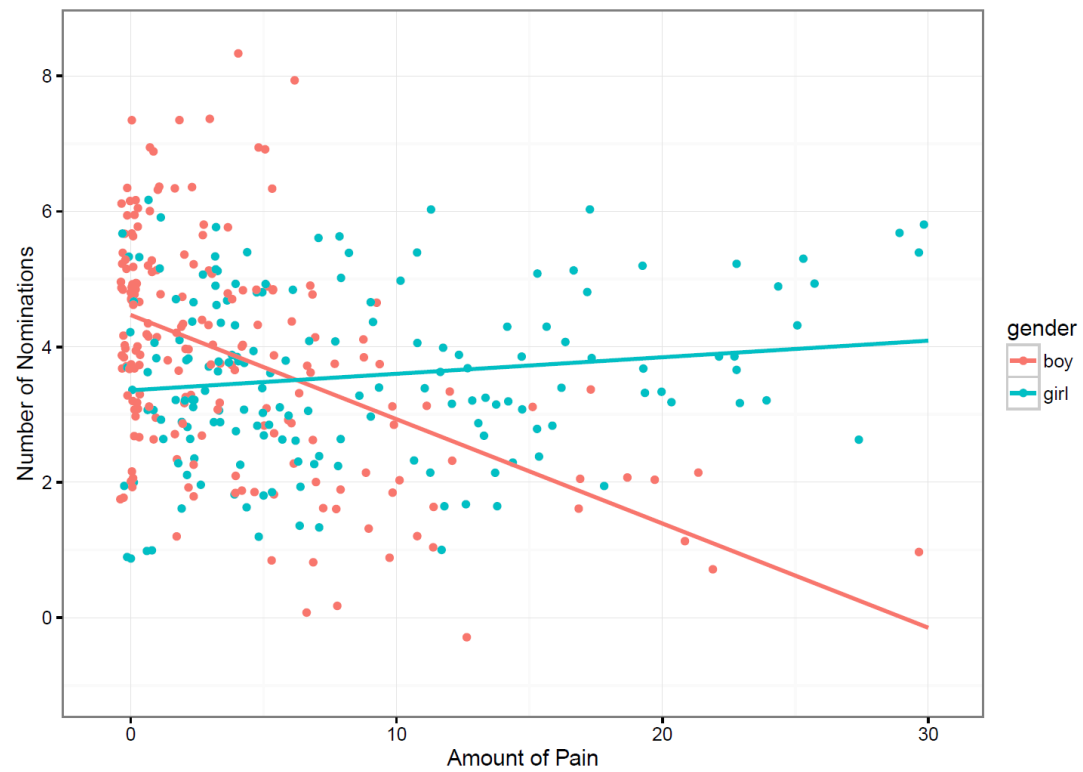


Figure 3

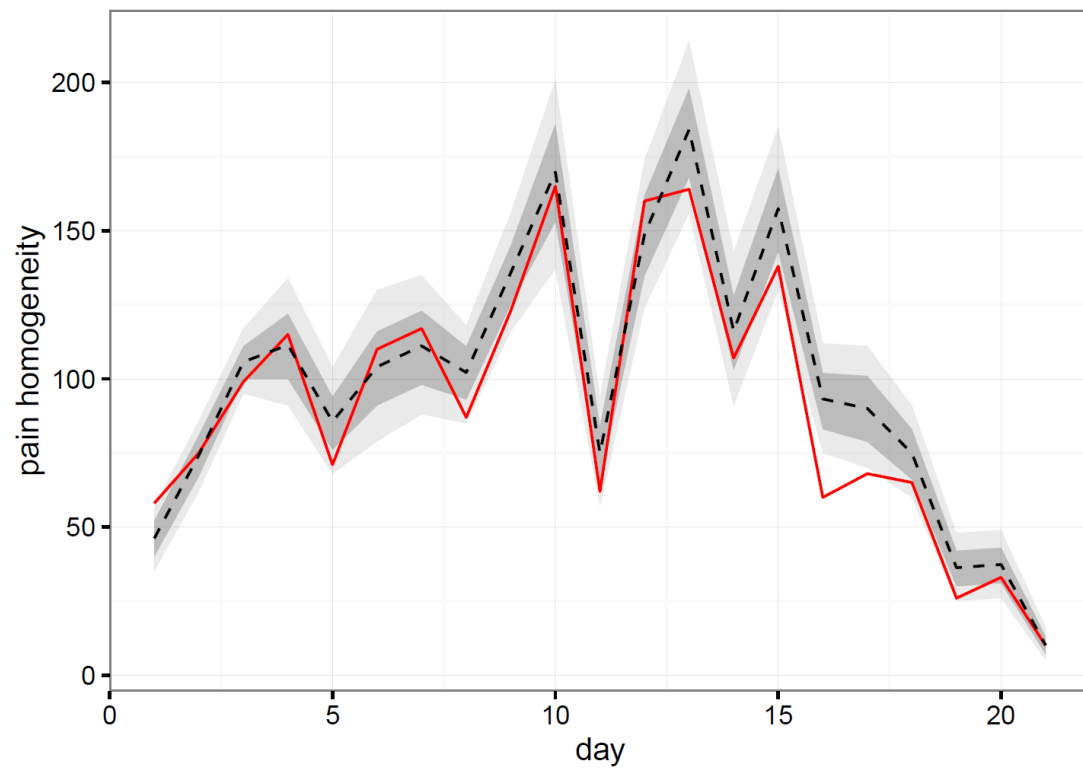


Figure 4

