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The Geography of Pain in the United States and Canada

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Abstract: Pain epidemiologists have, thus far, devoted scant attention to geospatial analyses of pain. Both cross-national and, especially, subnational variation in pain have been understudied, even though geographic comparisons could shed light on social factors that increase or mitigate pain. This study presents the first comparative analysis of pain in the U.S. and Canada, comparing the countries in aggregate, while also analyzing variation across states and provinces. Analyses are based on cross-sectional data collected in 2020 from U.S. and Canadian adults 18 years and older (N = 4,113). The focal pain measure is a product of pain frequency and pain interference. We use decomposition and regression analyses to link socioeconomic characteristics and pain, and inverse-distance weighting spatial interpolation to map pain levels. We find significantly and substantially higher pain in the U.S. than in Canada. The difference is partly linked to Americans' worse economic conditions. Additionally, we find significant pain variability within the U.S. and Canada. U.S. states in the Deep South, Appalachia, and parts of the West stand out as pain 'hotspots' with particularly high pain levels. Overall, our findings identify areas with a high need for pain prevention and management; they also urge further scholarship on geographic factors as important covariates in population pain.
***Perspective:** This study documents the high pain burden in the U.S. versus Canada, and points to states in the Deep South, Appalachia, and parts of the West as having particularly high pain burden. The findings identify geographic areas with a high need for pain prevention and management.*

***Key words:** Pain, comparative, geography, United States, Canada.*

The Geography of Pain in the United States and Canada

Our understanding of the epidemiology of pain remains incomplete. One critical gap is the paucity of research on the geographic distribution of pain, especially at sub-national, but also cross-national, levels. Our study provides the first detailed examination of the geographic distribution of pain both across and within the U.S. and Canada, using a relatively fine-grained pain measure that combines pain frequency and pain-related interference with daily activities.

The U.S. and Canada share many characteristics. Both are wealthy economies with highly educated, predominantly English-speaking, diverse populations and, according to most if not all classifications, share the "liberal" welfare-state regime designation.[2,44] At the same time, they differ in important ways. Canada has lower poverty rates, less socioeconomic inequality, a stronger social safety net, and, unlike the U.S., a

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universal health care system.[46,59] Perhaps as a result of these differences, studies often—although not always—find longer lifespans and better health in Canada.[19,24] However, no study to date has compared pain between these neighboring countries, or assessed the sources of any observed differences. Our U.S.-Canada comparison, therefore, offers insights about social factors shaping pain at the national levels.

Moreover, both countries are composed of sub-national units—states and provinces—that are increasingly heterogeneous with respect to health determinants.[23,36] These determinants include socioeconomic factors at the individual level, as well as specific policies and overall policy orientations at the state or province levels.[16,23] Correspondingly, states and provinces vary substantially in health and mortality rates.[33,37,65] For instance, the age-standardized prevalence of disability (defined as difficulty in activities of daily living such as dressing, bathing, or doing errands alone), an important and often pain-related dimension of health, is about 7% in Minnesota and North Dakota but over 13% in Kentucky or Mississippi.[38] Life expectancy also ranges widely across states and provinces, with a 6-year gap between the most and least healthy U.S. states,[1] and a 3 year gap across Canadian provinces [62] (or an 11-year gap if the Northern Territory of Nunavut is included[63]). However, research has neglected sub-national variability in pain and/or its predictors, as reflected by the paucity of studies on pain burden across states and provinces. Only a handful of publications have examined province-level variability in pain;[56,57] in the U.S., we are only aware of reports on the distribution of arthritis across U.S. states and counties.[3,4] This paucity is even more surprising and problematic when contrasted with the well-developed literature on geographic variability in opioid prescribing, opioid use (and misuse), and opioid-related mortality in both countries.[13,20,21,34,39,54,55]

Using a unique cross-sectional dataset collected in 2020 from U.S. and Canadian respondents, we answer two questions: 1) How is pain geographically distributed in the U.S. and Canada, both with respect to the two countries in aggregate and within each country across states and provinces?, and 2) How do population characteristics explain the observed patterns? Our findings reveal higher pain in the U.S. compared with Canada and link this excess pain to differences in economic well-being. We also identify U.S. pain "hotspots" with a particularly high need for pain prevention and treatment, a finding that we hope will pave the road for future studies on the contextual factors that explain excess pain in hotspot regions. Overall, the present findings invite researchers to consider geographic factors as important contributors to population pain.

Methods

Data

We use the Recovery and Resilience COVID-19 (RR) data.[64] This cross-sectional dataset was developed by an interdisciplinary team of social science investigators at the University of Western Ontario and administered by Leger Opinion in the U.S. and Canada in August 2020. The aim of the survey was to assess a range of sociopolitical, economic, and health-related factors during the early phase of the pandemic and compare population impacts in the two countries. The online survey was completed by 2,124 U.S. and 2,110 Canadian respondents aged 18 and older. The respondents were selected from a well-established, widely used, large (~500,000 person) ongoing Leger Opinion Panel using probability sampling within sex-age-region quota. Most respondents received a single email invitation to participate in our survey. The percentage who responded to the invitation email was 17% in Canada and 25% in the U.S. A small number of respondents were ineligible due to their age (below 18), or their responses were eliminated due to low quality; the final response rate was 13% in Canada and 19% in the U.S. The samples were designed to be nationally representative of age, gender, and Census region in the U.S. and provinces in Canada, and sampling weights were provided by Leger to correct for over- and under-sampling. We compared the RR data sample composition to the composition of the main health survey in each country: The National Health Interview Survey (NHIS) in the U.S. and the Canadian Community Health Survey (CCHS). Supplemental Table S1 shows that the Recovery and Resilience (RR) data resemble the CCHS distribution within a few percentage points in age, gender, race, education, and income. The Canadian RR sample includes fewer immigrants than the CCHS (19.3% vs 26.3%) and fewer employed adults (53.8% vs 58.0%). The U.S. RR sample included more men, Whites, and college-educated adults, and fewer Hispanic, immigrant, low-educated and employed adults, compared with NHIS. In the discussion section, we comment on the implications of the modest rate of response into our survey and the over- and under-sampling of select population groups, as well as the potential bias inherent in the selection into the Leger Panel. The survey was approved by the Ethics Board of the University of Western Ontario (Project ID 116046). The dataset and all documentation are available at https://dataverse.scholarsportal.info/dataset.xhtml?persistentId=doi:10.5683/SP3/5QHKJE.

Variables

The outcome is a continuous pain score, calculated from two questions. First, respondents were asked: "How often have you experienced pain in the past 30 days?" The response options were never or almost never, rarely, sometimes, often, almost always, and always (coded as 0−5). Respondents who indicated they had pain at least "rarely" were then asked: "How much did the pain interfere with your general activity like work or household chores? This item was originally assessed on an 11-point scale from "did not interfere"=1 to "completely interfered"=11; we additionally assigned a value of 0 interference for those who "never or almost never" experienced pain, as they were not posed the interference question. The correlation between these two items was high (Pearson r = .71 and Spearman r = .73). We also calculated an overall pain score as the product of pain frequency and interference, yielding a scale from 0 to 55. The score of 0 is for respondents who experienced pain "never or almost never," while 55 is for those reporting that they "always" had pain that "completely interfered" with their everyday activities. The pain score, as well as pain interference, had right-skewed distributions, which we found to be best modeled using negative binomial regressions. Pain frequency was reasonably symmetric and could be modeled using OLS.

We analyzed the continuous pain score, or its constituent parts, rather than dichotomizing them, as is often done in epidemiological research, for 2 reasons. First, dichotomizing a continuous outcome leads to a large loss of information and statistical power,[18] can result in misclassification or biased results,[47] and is "strongly discouraged."[17] Second, dichotomizing might have been worth these tradeoffs if it yielded well-validated measures of chronic pain or high-impact chronic pain, which we could compare against known estimates. Alas, our measures do not capture *chronic* pain, as they are assessed with respect to the past 30 days rather than the established 3 or 6 months.[68] Moreover, the RR response categories do not align with established ones: For instance, chronic pain is typically defined as pain on most days or every day, compared with never or some days. The RR measure of pain frequency has 6 levels, with no comparable threshold. We therefore analyze the pain measures as continuous; nonetheless, we present dichotomized descriptives in the Supplement for easier interpretation of the gross U.S. and/or Canada differences.

State or province of residence was reported by the respondents; U.S. respondents chose from a list of states and Canadian respondents from a list of provinces. Age was collected using the following categories: 18−24, 25−34, 35−44, 45−54, 55−64, and 65+. We collapsed the middle categories in descriptives and regression analyses for parsimony, generating categories of 18−24, 25−44, 45−64, and 65+. The collapsed and original specifications yielded substantively identical results. Gender was collected as male (reference), female, or other. Race was recoded to white (reference), Black, Hispanic, Asian, and other. Immigrant status was a dichotomy of native-born (reference) versus immigrant. Marital status was coded as married (reference, includes common-law), previously married, and never married. Respondents also reported whether they had children or not (reference). Education was coded as high school or less, some postsecondary education, associate degree or equivalent, and bachelor's degree or more (reference). Main activity status included categories for employed (reference), retired, unemployed, disabled, and other. Household income was assessed with the following prompt: "What was your total household income, before taxes, for the year 2019?" This question was answered by 2,992 or 71% of respondents. Those who did not provide the precise income were then asked: "We don't need the exact amount; does your household income fall into one of these broad categories?" This prompt included 8 categories from $0 to $200,000 or more. An additional 958 respondents (23%) responded to this item, yielding less than 7% missing cases. We used the midpoints of each category from this 8-level income and combined them with the continuous income measure. We then used Purchasing Power Parity for 2019 and 2020[48,61] and converted the Canadian incomes to be equal to the U.S. incomes (the Canadian incomes were divided by 1.206); the resulting variable was logged before imputation. We used the logged income in the regression and decomposition analyses. For the descriptives, we categorized income into four levels after back-transforming it by exponentiating. Finally, respondents were asked about financial hardship due to COVID-19, which can be viewed as an additional indicator of economic conditions. This was measured with the question "Are you feeling financial hardship due to COVID-19?" and coded as no hardship (reference), little or slight hardship, some hardship, or serious hardship.

Approach

Our approach had three sequential analytic steps. First, we calculated univariate and bivariate (U.S. versus Canada) descriptive statistics. Specifically, we estimated weighted pain scores in each country for the total population, as well as separately for each sociodemographic group; we also tested whether the pain scores differed between the two countries using group-specific bivariate weighted negative binomial regression models of the pain score on a country indicator (Table 1). We included a comparison of the pain outcomes between the U.S. and Canada for pain score, frequency, and interference, as well as their dichotomized versions using different thresholds as robustness checks (Supplemental Table S2). We also show the full distribution of all covariates in each country and test for differences in the distributions between the two using design-adjusted F-tests (Supplemental Table S3).

In the second analytic step, we analyzed differences in pain scores between the U.S. and Canada in aggregate, using two complementary approaches: nonlinear decomposition (Table 2) and a series of regression models (Supplemental Table S4). The Oaxaca-Blinder nonlinear decomposition is a widely used econometric method that quantifies how much of the difference in the pain scores between the U.S. and Canada is a function of different population characteristics (composition) or different coefficient effects (also referred to unexplained part).[5,45] More formally, the observed difference in pain prevalence $\overline{y}_{US} - \overline{y}_{Can}$, where $\overline{y}_{US}$ is the mean pain level in the U.S. and $\overline{y}_{Can}$ is the mean pain level in Canada, is defined as $\overline{y}_{US} - \overline{y}_{Can} = F(X_{US}\hat{\beta}_{US}) - F(X_{Can}\hat{\beta}_{Can})$, where the X_{US} and X_{Can} are vectors of observed covariates in the U.S. and Canada, respectively. Their associated vectors of coefficients $\hat{\beta}$s are estimated using a negative binomial model appropriate to the skewed positive distribution of the pain scores, and $F()$ is the cumulative

Table 1. Mean pain scores in the U.S. and Canada for the total sample and in each subgroup.

	U.S.		Canada		P value from Wald test of difference
Pain score in full sample	12.5	(11.9, 13.0)	10.7	(10.1, 11.2)	<.001
Pain score, by age					
18−24	7.7	(6.4, 9.0)	8.0	(6.8, 9.1)	.785
25−44	13.5	(12.3, 14.7)	10.1	(9.2, 10.9)	<.001
45−64	13.7	(12.6, 14.9)	11.4	(10.4, 12.3)	.002
65+	11.2	(9.8, 12.5)	11.7	(10.5, 13.0)	.553
Pain score, by gender					
Men	11.6	(10.7, 12.6)	9.6	(8.9, 10.3)	<.001
Women	13.3	(12.4, 14.2)	11.6	(10.9, 12.4)	.005
Pain score, by race/ethnicity					
Non-Hispanic white	13.1	(12.3, 13.9)	11.1	(10.5, 11.7)	<.001
Non-white	10.5	(9.3, 11.7)	9.3	(8.4, 10.3)	.131
Pain score, by immigrant status					
Not immigrant	12.8	(12.1, 13.5)	11.0	(10.4, 11.6)	<.001
Immigrant	8.2	(6.1, 10.2)	9.3	(8.3, 10.3)	.352
Pain score, by education					
High school or less	13.0	(11.5, 14.5)	12.8	(11.5, 14.2)	.877
Some postsecondary	14.5	(13.0, 15.9)	11.8	(10.5, 13.1)	.007
AA or VTC	13.5	(11.6, 15.5)	13.4	(12.0, 14.7)	.907
BA or higher	10.9	(10.0, 11.8)	8.1	(7.5, 8.7)	<.001
Pain score, by main activity					
Employed	11.2	(10.4, 12.1)	9.3	(8.7, 9.9)	<.001
Retired	12.1	(10.5, 13.7)	11.9	(10.7, 13.1)	.874
Unemployed	12.9	(10.6, 15.1)	11.5	(9.3, 13.7)	.395
Disabled	25.8	(22.7, 28.9)	32.3	(28.0, 36.5)	.014
Other	11.3	(9.7, 12.9)	9.0	(7.8, 10.2)	.025
Pain score, by family income					
0-24k	15.7	(14.3, 17.0)	14.0	(12.6, 15.3)	.092
25-49k	11.8	(10.4, 13.2)	11.9	(10.8, 13.0)	.931
50-99k	11.1	(10.0, 12.3)	9.6	(8.8, 10.4)	.028
100k or more	10.3	(9.0, 11.5)	7.5	(6.6, 8.3)	<.001
Pain score, by financial hardship*					
No hardship	9.5	(8.5, 10.4)	8.1	(7.4, 8.8)	.017
Slight/little hardship	12.2	(11.3, 13.2)	10.8	(10.0, 11.5)	.018
Some hardship	14.7	(12.8, 16.6)	16.4	(14.5, 18.4)	.213
Serious hardship	22.5	(19.6, 25.5)	19.5	(16.1, 23.0)	.203

Abbreviations: AA, associate degree; VTC, vocational/technical credential; BA, bachelor's degree.
NOTE. Recovery and Resilience (RR) data, N=4,113.
Weighted means and 95% confidence intervals. Pain score is a continuous variable with 0-55 range.
The *P* values are from Wald tests for a U.S. dummy (versus Canada) in weighted negative binomial bivariate regressions of pain estimated separately for each group.
*Financial hardship due to COVID-19.

distribution function of the negative binomial distribution. The term $F(X_{US}\hat{\beta}_{Can})$ can be added and then subtracted to obtain: $\bar{y}_{Can} - \bar{y}_{US} = [F(X_{Can}\hat{\beta}_{Can}) - F(X_{US}\hat{\beta}_{Can})] + [F(X_{US}\hat{\beta}_{Can}) - F(X_{US}\hat{\beta}_{US})]$. The first bracket captures the gap between the two countries related to differences in population characteristics, while the second bracket captures the component related to differences in coefficients. We used the *mvdcmp* extension in Stata for decomposition,[50] combined with the new utility for grouping individual covariates for detailed decomposition, *mvdcmpgroup* (Powers 2020, personal communication). The effects of categorical variables in this approach are normalized as deviations from the grand mean, which enables the calculation of effects for all levels, and yields results that are identical regardless of which category is the reference.[28] In Supplemental Table S4, we present analogous results using a series of weighted negative binomial regression models of the pain score with an indicator for the U.S., net of different sets of covariates. This approach is widely used but has several weaknesses, including that the effect of all covariates is constrained to be equal in both countries, which is effectively equivalent to forcing the coefficient effect (unexplained part) in the decomposition to be equal to zero.

The third step was to examine the pain scores at the level of sub-national units, that is, states in the U.S. and provinces in Canada. First, we mapped the geographic distribution of weighted mean pain scores in the U.S. and Canada (Fig 1). The inverse distance weighting (IDW) spatial interpolation technique[32] was used to estimate pain scores for unsampled locations using values from surrounding locations, thereby generating a continuous surface of weighted mean pain scores across the U.S. and Canada. Supplemental Figure S1 shows the pain scores adjusted for age and sex. We obtain the adjusted scores by calculating residuals from weighted negative binomial model of the pain score as a function

Table 2. Nonlinear decomposition of the pain score difference between US and Canada related to differences in population composition versus differences in coefficient effects.

	Linked to composition differences (%)	Linked to coefficient differences† (%)
Total decomposition	71.8***	28.2
Detailed		
Age and sex	5.3**	4.9
Race and immigrant status	28.0**	29.5
Marital and parent status	3.9	-2.5
Education	-0.9	12.7*
Economic factors	35.4***	16.5

NOTE. Recovery and Resilience (RR) data, N=4,113.
The approach decomposes the difference in mean pain score in the U.S. (12.5) versus in Canada (10.7) into a part linked to differences in population characteristics (composition) and a part linked to differences in coefficients (that is, the effects of the coefficients on pain). The group "Economic factors" includes main activity, family income, and financial hardship due to COVID-19.
*$P < .05$.
**$P < .01$.
***$P < .001$.
†This part of the difference is also referred to as the unexplained part.

of age and sex, then calculating the average in each state or province, and mapping the averages. Supplemental Figure S2 and S3 show the interpolated map for pain frequency and pain interference, respectively, while Supplemental Figures S4-S6 plot the pain score, pain frequency, and pain interference scores on a choropleth map, that is, plotting state-average values in each state (with at least 15 respondents). Table 3 provides a different perspective on the state and/or variation in pain scores: it lists the weighted mean pain scores and their 95% confidence interval for each state and/or province with at least 15 respondents, ranked from highest to lowest score. Supplemental Tables S5 and S6 show the state and province-level descriptives for average pain frequency and pain interference values. Finally, we tested whether the pain scores vary significantly across all subnational units via likelihood ratio F-tests of joint significance (Supplemental Table S7). For complete reference, Supplemental Table S8 shows the number of respondents in each state and province.

Missing data were imputed using multiple imputation via chained equations[53] implemented using the suite of Stata's mi commands.[60] Age, gender, race, employment status, pain frequency, and pain interference had no missing values. Immigrant status was missing for 12 respondents (0.3%), marital status for 24 (0.6%), parental status for 21 (0.5%), educational attainment for 6 (0.1%), financial hardship for 82 (2.0%), and income for 243 respondents (5.9%). Age, gender, race, employment status, pain frequency, and pain intensity were used as predictors in logit models for immigrant and parental status, a multinomial logit model for marital status, ordered logit models for educational attainment and financial hardship, and predictive mean matching for household income. We created 20 imputed datasets for the regression analysis. We also randomly selected one imputed dataset for the descriptive and decomposition analyses. The findings were substantively the same as with complete-case analyses, unsurprising given the low overall proportion of missingness (91.9% of respondents had no missing information, and an additional 7.1% had only one missing variable), and the fact that post-imputation checks for income, the variable with most missing cases, showed a similar distribution of imputed and unimputed values.

All analyses were weighted. Data cleaning, descriptives, decomposition, and regression analyses were conducted in Stata 17; mapping was done in ArcMap 10.8.1.

Results

Part 1. Descriptives − National Level

Table 1 summarizes weighted mean pain scores in the U.S. and Canada, both in aggregate and in population subgroups. In the total sample, the mean pain score was 12.5 (95% CI 11.9, 13.0) in the U.S. and 10.7 (95% CI 10.1, 11.2) in Canada, a statistically significant difference ($P < .001$). Among specific population subgroups, pain scores were always either statistically significantly higher in the U.S., or not significantly different; put differently, pain scores were never significantly higher in Canada. The differences were largest for white, non-immigrant, college-educated, employed, high-income, and no financial hardship groups. The differences were smaller and not significant among non-whites, immigrants, individuals without college degrees or with sub-baccalaureate degrees (ie, associate degrees or vocational and/or technical certificates), individuals with lower income, and those experiencing some or serious financial hardship due to COVID-19.

The groups with the highest average pain scores in both countries were those who reported serious financial hardship due to COVID-19 (with average pain scores of 22.5 in the U.S. [95% CI 19.6, 25.5] and 19.5 in Canada [95% CI 16.1, 23.0]), and respondents who described their main activity status as "disabled" (25.8 in the U.S. [95% CI 22.7, 28.9] and 32.3 in Canada [95% CI 28.0, 36.5]). The lowest pain scores were among young adults aged 18−24, as well as immigrant and non-white respondents, and those with household incomes above $100,000 and no financial hardship.

Supplemental Table S2 adds detail to the U.S. and/or Canada aggregate pain comparison by showing the mean pain frequency and interference scores in addition to the pain score, as in Table 1, and dichotomizing all 3 pain dimensions using at least 2 thresholds. For each of these specifications, pain was significantly higher in the U.S.; for instance, 16.3% of American respondents [95% CI 14.4%, 18.1%] but only 11.3% of Canadians [9.9%, 12.7%] had pain almost always or always in the past 30 days. In fact, across all seven dichotomous pain specifications, U.S. adults consistently had 4.0−6.4 percentage point higher prevalence than Canadians.

Part of this difference could be related to different population characteristics. Supplemental Table S3

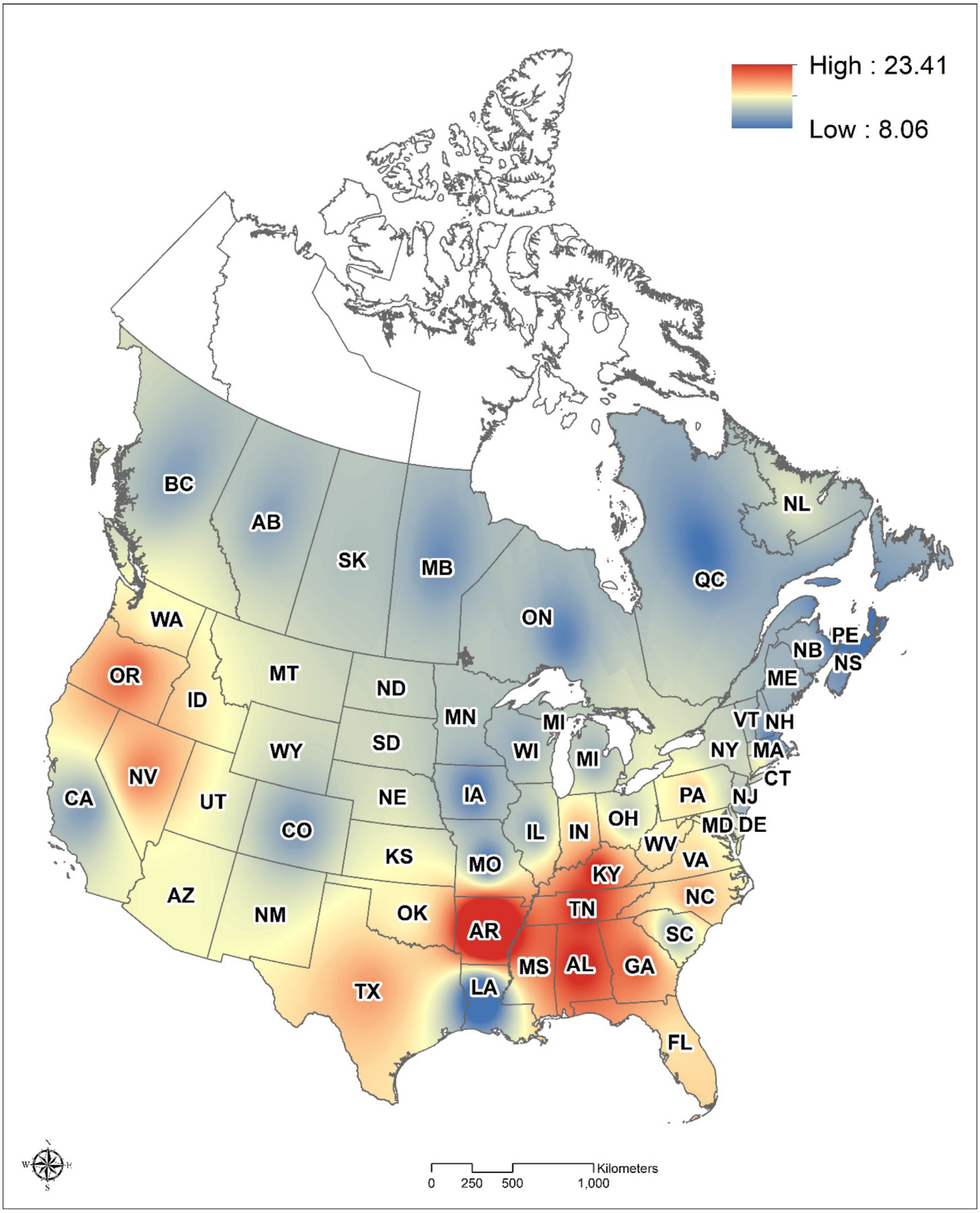

Figure 1. Weighted mean pain scores in U.S. states and Canadian provinces. Note. The map visualizes weighted mean pain scores (range 0–55) in U.S. states and Canadian provinces. The continuous surface is estimated using the inverse distance weighting (IDW) spatial interpolation approach. Source: Recovery and Resilience (RR) data, N = 4,113.

summarizes the distribution of all included characteristics in the U.S. and Canadian samples and shows *P* values from tests for differences in the distribution of each covariate between the countries. The 2 samples differ with respect to several demographic characteristics, in particular race and/or ethnicity and immigrant status, but also gender. The U.S. adult population comprises more Black and Hispanic respondents than the Canadian population, whereas Asian Canadian and "other" groups predominate among Canadian non-white groups. Additionally, the U.S. sample includes 7.5% immigrant adults, compared to 19.3% in Canada. Race and/or ethnicity and immigrant status matter greatly in analyses of pain as immigrants report less pain than native-born adults, at least in the U.S.[73,74] There are also important racial/ethnic differences in pain prevalence as well,[41,49,72] with adults of Asian heritage tending to report particularly low pain prevalence.[31,40] With respect to gender, pain differences are well known; women report greater pain prevalence, severity, and

Table 3. Weighted mean pain score and 95% CIs in U.S. states and Canadian provinces (with 15 or more respondents), ranked from highest to lowest mean pain score

	Mean pain score	95% CI		Mean pain score	95% CI
Arkansas	23.4	(15.7,31.2)			
Tennessee	17.1	(12.9,21.4)			
Alabama	16.9	(10.9,22.9)			
Kentucky	16.8	(11.6,22.1)			
Kansas	16.5	(6.3,26.6)			
Mississippi	16.4	(9.5,23.3)			
Georgia	15.8	(11.5,20.2)			
Oregon	15.6	(11.5,19.7)			
Nevada	15.1	(8.0,22.3)			
North Carolina	14.8	(11.1,18.5)			
Texas	14.7	(12.5,16.9)			
Indiana	14.1	(9.1,19.0)			
Pennsylvania	14.0	(10.7,17.2)			
Virginia	13.7	(9.9,17.5)			
Florida	13.6	(11.3,15.8)			
Oklahoma	13.2	(5.2,21.3)			
Maryland	13.2	(7.8,18.6)			
Connecticut	13.1	(8.3,17.9)			
Washington	13.1	(9.9,16.3)			
Arizona	13.1	(9,17.1)			
			Newfoundland & Labrador	12.7	(7.4,18.1)
New York	12.2	(10.1,14.4)			
Ohio	12.0	(9.2,14.8)			
Minnesota	11.9	(5.9,17.9)			
			Saskatchewan	11.9	(8.8,14.9)
			New Brunswick	11.8	(7.9,15.8)
New Jersey	11.5	(8.0,15.0)			
Michigan	11.4	(8.4,14.5)			
Wisconsin	11.3	(7.3,15.3)			
			Alberta	11.3	(9.6,12.9)
South Carolina	11.3	(7.3,15.3)			
			British Columbia	11.2	(9.8,12.6)
California	11.2	(9.5,12.8)			
Illinois	11.1	(8.9,13.3)			
Colorado	11.1	(5.4,16.7)			
			Nova Scotia	11.1	(8.2,13.9)
			Manitoba	10.7	(8.0,13.4)
			Ontario	10.4	(9.6,11.3)
Massachusetts	10.3	(6.1,14.5)			
Missouri	10.3	(6.7,13.9)			
Iowa	10.2	(3.9,16.5)			
			Quebec	10.0	(9.0,11.1)
Louisiana	8.2	(4.2,12.3)			
			Prince Edward Island	8.1	(1.5,14.6)

NOTE. Recovery and Resilience (RR) data, N = 4,113.
Each pain summary measure is color-coded from the highest (red) to lowest (green). The order is based on the mean pain score. The summary statistics are estimated using sampling weights.

interference, compared with men.[6,51,67] Thus, intercountry differences in race and/or ethnicity, immigrant status, and gender may shape overall country differences in pain. The U.S. and Canadian samples also differ in socioeconomic status indicators. The U.S. has significantly lower educational attainment and household income, and U.S. respondents reported significantly greater financial hardship due to COVID-19 (all $P < .001$). Given that socioeconomic status is 1 of the most important social factors in pain,[27,35,52] we next examine how these various sociodemographic differences may impact pain in both countries.

Part 2. Analysis of Pain Score Differences Between the U.S. and Canada − National Level

The second step was to analyze the sources of the pain differences between the U.S. and Canada. Table 2 shows the proportion of the observed pain score differences that can be linked to differences in composition (population characteristics) versus differences in coefficient effects (the unexplained part). The total decomposition shows that 71.8% of the gap in the mean pain scores between the two countries is related to differences in composition (characteristics) while 28.2% is unexplained; that is, related to differences in coefficient effects or unobserved factors. The detailed decomposition shows how the covariates, grouped for parsimony, add up to these totals. Over a third of the compositional difference is linked to economic factors, (ie, main activity, household income, and financial hardship [35.4%, $P < .001$]), meaning that different distributions of economic characteristics contribute significantly to the observed pain difference. As we summarized in Supplemental Table S2, U.S. respondents have lower household income and greater prevalence of financial hardship than their Canadian counterparts. The second major source of the U.S. and/or Canada pain difference is linked to differences in race and immigrant status composition (28.0%, $P < .01$). This is also unsurprising given the high proportion of Canadians who are immigrants or Asian Canadians − characteristics associated with particularly low pain prevalence, as noted in the prior paragraph.

Supplemental Table S4 corroborates this picture with a set of regression models of pain scores as a function of the U.S. indicator and covariates. This set of models effectively constrains the effect of all covariates to be equal in the U.S. and Canada since interaction terms are not included; however, this constraint is reasonable since the decomposition analysis found no overall statistically significant difference in the coefficient effects. The models show significantly higher pain score in the U.S. relative to Canada, whether or not we control for age and gender (Models 1 and 2, prevalence ratio (PR) = 1.17, 95% CI 1.09, 1.26). Race and immigrant status attenuate the U.S. pain disadvantage somewhat (PR = 1.13, CI 1.05,1.22 in Model 3). Marital and parental status have no measurable effect on the country difference, while controlling for education makes the U.S. disadvantage slightly greater (PR = 1.16, CI 1.07, 1.25 in Model 5). Further, economic characteristics are particularly salient in attenuating the U.S. and/or Canada difference (PR = 1.07, CI 0.99, 1.15 in Model 6 without education and PR = 1.10, CI 1.02, 1.18 in Model 7 with education).

In sum, the decomposition and regression analyses show that a large part of the higher pain score in the U.S., as compared to Canada, is related to worse economic conditions among U.S. adults, and, to a smaller degree, to racial/immigrant compositional differences between the two countries.

Part 3: Analysis at Sub-National (State and Province) Levels

The analyses thus far have treated both countries as monolithic units, when in reality they comprise heterogeneous subnational areas. Therefore, we next examine how pain varies within each country across states and provinces. Fig 1 shows a map of weighted mean pain scores in the U.S. and Canada. The map highlights the relatively low average pain scores across much of Canada (blue hue), as well as across much of the U.S. Midwest and Northeast. The figure also highlights that pain is substantially higher in much of the U.S. Deep South and parts of Appalachia, as well as select areas of the West and Northwest such as Oregon and Nevada (red hue). Supplemental Figures S1-S6 show similar patterns across different specifications of the pain variable, different mapping techniques, and whether or not we control for age and sex distributions.

We also tabulated the state/province data. Table 3 shows the mean pain scores and their 95% confidence intervals in each state or province with at least 15 respondents, ordered from highest to lowest mean scores. The left panel in the table lists U.S. states; the right panel lists Canadian provinces. The average pain scores in U.S. states range from roughly 10 points in Iowa, Missouri, and Massachusetts, to about 17 or more in Arkansas, Tennessee, Alabama, and Kentucky. Louisiana had the lowest pain score, at 8.2 [95% CI 4.2, 12.3], which we interpret with great caution given the state's small number of respondents (21, see Supplemental Table S8) and overall poor health.[66] The range of pain scores across Canadian provinces is much smaller. Here, the pain scores range from about 8−10 in Prince Edward Island, Quebec, and Ontario, to less than 13 in Newfoundland and Labrador. Thus, all Canadian provinces have pain scores on par with the lower half of U.S. states or, put differently, about half of U.S. states have pain scores higher than *any* province in Canada. Supplemental Tables S5 and S6 shows parallel findings for mean pain frequency and pain interference values, respectively.

Finally, we checked whether the pain scores differ significantly across the sub-national units, by testing the joint effects of U.S. states, Canadian provinces, and all subnational units jointly, with F tests across negative binomial regression models of pain scores. Supplemental Table S7 summarizes the results. The variation is significant in the null bivariate model ($P < .05$) and marginally when we control for age and sex ($P < .10$) when we analyzed all sub-national units, that is, states and provinces together. When we control for additional characteristics, however, the joint effect of sub-national units is not significant. The variation is not statistically significant for any U.S. and Canada-specific models, perhaps because of the relatively modest sample sizes for most sub-national units.

Discussion

The Federal Pain Research Strategy has declared that the "greatest near-term value" research priority to understand pain disparities is to "better define the epidemiology of pain in disparate populations," and the "most impactful top priority" is to investigate mechanisms, including social mechanisms, that contribute to group differences in pain burden.[26, p. 18] Our analysis contributes directly to these priorities. Using a large, new, cross-sectional international survey, we compared population pain levels in the United States and Canada at the aggregate national level and tested social correlates of observed differences. Furthermore, we examined geographic variation in pain *across* states and provinces and identified hotspots with particularly high pain levels.

We found that pain is significantly higher among U.S. adults compared with Canadian adults. The difference is substantively large: 4−6 percentage point higher pain prevalence in the U.S. compared with Canada across different pain components and thresholds. This difference translates to roughly 10 million extra U.S. adults experiencing pain compared to what would be observed if U.S. pain were at Canadian levels. While ours is the first comparative study of pain in these two countries, the results corroborate previous findings of overall worse health and higher mortality in the U.S.[7,19,24]

We also noted an interesting pattern wherein the U.S. pain excess tended to be largest for more advantaged groups, such as those with the highest education and incomes, while the pain score differences were smaller and not statistically significant among disadvantaged groups (ie, adults who were non-white, immigrants, or less educated, or who had lower household incomes or greater financial hardship). This pattern stands in contrast to prior U.S.-Canada comparisons of other health dimensions, which tend to find equal or larger differences among more disadvantaged groups.[25,58,75] It is unclear why more advantaged Americans report greater levels of pain than more advantaged Canadians; perhaps this is due to different treatment regimens or reporting differences. This unexpected pattern should be investigated further.

The higher pain burden in the U.S. versus in Canada is related to the significantly worse economic conditions among U.S. adults, including greater likelihoods of low income and financial hardship. The importance of economic factors in the between-country differences corroborates the well-documented impact of economic conditions on physical pain at the individual level.[8,29,35,69,70] Additionally, the counterfactual decomposition showed that the effects of socioeconomic factors on pain were comparable in the U.S. and Canada. This is an important finding because it confirms the link between socioeconomic factors and pain burden at a national level, which, in turn, contributes foundational evidence regarding the social roots of pain.

The pain patterns were more complex at the subnational level. We found variation across states and provinces, although the variation was statistically significant only for all sub-national units together, not when U.S. states and Canadian provinces were examined separately. In Canada, pain scores ranged from about 8−10 in Quebec, Ontario, and Prince Edward Island, to around 12−13 in the Atlantic provinces of Newfoundland and Labrador and New Brunswick; the Prairies and the Canadian West were roughly in the middle. This general geographic pattern fits the findings of the only prior study we are aware of that estimated province-specific pain prevalence using a large, nationally-representative Canadian health survey.[56] The pain scores ranged more widely in the U.S., from about 10 in Iowa, Missouri, and Massachusetts, to over 23 in Arkansas. Overall, about half of U.S. states had pain burden within the range observed across Canadian provinces, while the other half had higher pain than found in *any* Canadian province.

Indeed, some U.S. states had such high pain burden relative to all other sub-national units (pain score ≥ 15) that we designated these states as pain "hotspots." These comprise the primarily Southern and Appalachian states of Arkansas, Tennessee, Mississippi, Alabama, Kentucky, Georgia, as well as Kansas, and the Western states of Oregon and Nevada.

To our knowledge, there are no prior analyses of pain burden across U.S. states to which to compare our findings; indeed, the majority of studies on U.S. population pain burden include no geographic indicators.[9,14,22,76] Several studies have described U.S. pain by Census region and report higher prevalence of pain in the South[42] or West,[30,74] and less in the Northeast.[42,73] Analyses of arthritis[3,4] also note high prevalence in the Deep South and Appalachia regions. Our findings are generally consistent with these patterns, as well as with geographic patterns in other dimensions of health, which include particularly high rates of mortality,[37,71] disability,[38] and risk factors such as smoking[10] and obesity[11] in the Deep South and Appalachian states.

The lack of research on geographic variation in population *pain* is particularly surprising when contrasted with the much more thorough documentation of variation in pain *treatment*, especially opioid prescribing, use, and misuse (including overdoses and mortality), across U.S. states and Canadian provinces. Importantly, the hotspot areas we identified with respect to pain overlap with areas of high opioid use (ie, Appalachia and the South,[12] and states in the Pacific Northwest[34,55]). Whether this overlap is coincidental, causal, or confounded by common causes, it requires further investigation, and we urge the collection and public-use dissemination of data that would enable scholars to examine the geography of pain in more detail.

Our conclusions are limited by four factors: sample size, representativeness, cross-sectional study design, and the operationalization of pain. First, our total sample exceeds 4,000 (with over 2,000 respondents in each country), but the sub-national analyses, especially for U.S. states, should optimally be based on a larger sample. Thus, our conclusions about any single state, especially outliers like Arkansas and Louisiana (both of which had only 21 respondents), must be viewed as provisional. Louisiana's low pain burden was particularly unexpected given its low position in health and longevity rankings.[38,43,66] We note that pain levels in Louisiana were not actually the lowest in our dataset. Rather, states including South and North Dakota, Hawaii, and Utah had lower pain scores, as could be expected on the basis of their overall healthy profiles.[38,43] However, these other states included fewer than 15 respondents, which we set *a priori* as a threshold for presenting state-specific findings. Second, concerns about the representativeness of both samples limit the generalizability of our results. The online study design excludes adults without access to broadband internet, smartphones, or computers, and the survey's modest response rate further raises the possibility of biased selection into our analysis. The sampling weights adjust for age, sex, and region/province distribution, but not for SES or other characteristics, and the comparison of our sample with large national studies suggests some departures from representativeness: the most disadvantaged population segments in each country appear to be underrepresented. Thus, our pain scores likely underestimate the true burden since the omitted disadvantaged adults would likely report higher pain.[15,74] On the other hand, there is no reason to suspect that the selection processes would differ between the U.S. and Canada, meaning the comparisons are unlikely to be biased. Moreover, the invitation to our study did not mention pain; therefore, there should be no outcome-related bias in the selection. Third, we note that the cross-sectional study design precludes us from drawing any causal inferences about the direction of causality between economic circumstances and pain. This is an important caveat because a 'reverse' direction of causality, whereby pain causes declines in economic wellbeing, would imply that improving economic circumstances would not necessarily lead to pain reduction. And fourth, the non-standard operationalization of pain in our survey limits its comparability to existing population studies. It is important not to interpret our findings as capturing chronic pain or high-impact chronic pain, since we lack measures or proxies of chronicity. We thus intentionally present all our results as describing "pain" broadly. We hope that another cross-national study can be conducted with standard, validated pain measures to position the international and subnational results within known national-level estimates of chronic pain.

Conclusion

Population pain is higher in the U.S. than in Canada, a difference largely linked to worse economic conditions among U.S. adults. While based on associational analysis precluding a causal interpretation, this finding clearly merits further investigation. Additionally, pain differences across states and provinces are even larger than the differences between the 2 countries. In particular, we identified a portion of U.S. states in the Deep South, parts of Appalachia, and parts of the West as pain "hotspots." We posit that state policy orientation and contexts might help explain the hotspots' excess pain. Future research should draw on cross-national and subnational variation in pain as an important lens to uncovering the macro- to individual-level social roots of population pain.

Supplementary data

Supplementary data related to this article can be found at https://doi.org/10.1016/j.jpain.2022.08.002.

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