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Frailty differences across population characteristics associated with health inequality: a cross-sectional analysis of baseline data from the Canadian Longitudinal Study on Aging (CLSA)

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ABSTRACT

Objective To evaluate the pattern of frailty across several of social stratifiers associated with health inequalities.

Design, setting and participants Cross-sectional baseline data on 51 338 community-living women and men aged 45–85 years from the population-based Canadian Longitudinal Study on Aging (collected from September 2011 to May 2015) were used in this study.

Primary outcomes and measures A Frailty Index (FI) was constructed using self-reported chronic conditions, psychological function and cognitive status and physical functioning variables. Social stratifiers were chosen based on the Pan-Canadian Health Inequalities Reporting Initiative, reflecting key health inequalities in Canada. Unadjusted and adjusted FIs and domain-specific FIs (based on chronic conditions, physical function, psychological/cognitive deficits) were examined across population strata.

Results The overall mean FI was 0.13±0.08. It increased with age and was higher in women than men. Higher mean FIs were found among study participants with low income (0.20±0.10), who did not complete secondary education (0.17±0.09) or had low perceived social standing (0.18±0.10). Values did not differ by Canadian province of residence or urban/rural status. After simultaneously adjusting for population characteristics and other covariates, income explained the most heterogeneity in frailty, especially in younger age groups; similar patterns were found for men and women. The average frailty for people aged 45–54 in the lowest income group was greater than that for those aged 75–85 years. The heterogeneity in the FI among income groups was greatest for the psychological/cognitive domain.

Conclusions Our results suggest that especially in the younger age groups, psychological/cognitive deficits are most highly associated with both overall frailty levels and the gradient in frailty associated with income. If this is predictive of later increases in the other two domains (and overall frailty), it raises the question whether targeting mental health factors earlier in life might be an effective approach to mitigating frailty.

Strengths and limitations of this study

► The large population-based sample with sampling weights making the results generalisable to middle-aged and older community-living adults in Canada.
► The use of multiple population stratifiers associated with social inequalities.
► The use of the LMG statistic to assess the relative amount of heterogeneity in the Frailty Index explained by different social stratifiers adjusted for each other and relevant covariates.
► The cross-sectional nature of the data does not allow for causal inferences.
► Sampling bias may be present, as participants were generally healthy volunteers residing in the community.

BACKGROUND

Frailty is recognised as a multidimensional concept with dynamic inter-related physical, psychological, social and environmental deficits associated with increasing levels of vulnerability and declining reserve.1 Frailty levels generally increase with age, are higher in women and are associated with an increased risk for both current and future disability, falls and fractures, mortality and other adverse health outcomes.2-4 Frailty level is also a strong predictor of health and social care utilisation such as emergency department visits and hospitalisations and hospital readmissions,5 as well as receiving informal care.6 By 2050, the world’s population aged 60 years and older is expected to total 2 billion, up from 900 million in 2015, and 125 million people aged 80 years or older. With this demographic transition, frailty is an emerging public health priority7,8 and there has been an increasing interest to consider

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the importance of upstream social, in particular, socioeconomic status (SES) factors to help understand the heterogeneity in frailty across the population spectrum.9

Researchers have found a relationship between SES and health indicators with generally worse health associated with lower SES measured by different social determinants, such as income, wealth and education.10 11 Link and Phelan proposed that social factors such as SES are a ‘fundamental cause’ of disease.12 The magnitude of the gap between lower and higher SES groups, however, has been found to differ by sex and vary with age.13–15 There are two main theories regarding this changing relationship between SES and health indicators with ageing. The first is that the impact of SES is cumulative with increasing divergence between SES groups with ageing (cumulative disadvantage) while the second holds that early divergence is followed by convergence later in life (age-as-a-leveler).16

There is conflicting evidence on whether differences in frailty status across SES groups decrease, stay the same or increase with age.17–19 The conflicting evidence may be due in part to differences in the social stratifiers used to explain heterogeneity across studies. For example, Stolz et al18 found that health inequalities due to education, occupation and wealth (ie, the household net worth including real estate and financial assets) tended to persist throughout old age whereas the effect of income (ie, wages, pensions and social transfers) declined. In addition, the magnitude of the gap between physical health and psychological health indicators has been shown to differ with age.10 14 20 This is relevant as frailty is multidimensional and is often measured by the Frailty Index (FI) which incorporates deficits from a range of body systems, including chronic conditions, physical, psychological and cognitive factors, but the specific deficits included and the number of deficits per body system generally differ by study.21 To help understand what factors may be associated with the conflicting evidence, a comprehensive assessment of multiple social stratifiers and decomposition of frailty into subdomains including chronic conditions, physical, psychological and cognitive factors is needed.

Understanding why some people are frail while others are not, or the heterogeneity in frailty, has significant public health importance.22 Our recent context of the disproportional impact of COVID-19 on older adults and increasing evidence that social inequalities are profoundly impacting COVID-19 morbidity and mortality has heightened this importance.23 To understand this, however, requires a very large data set to disentangle which factors best explain the heterogeneity in frailty and whether the patterns across social stratifiers differ by sex and age group. In this study we examined the heterogeneity of a FI across several of social stratifiers associated with health inequalities in a population of over 50 000 middle-aged and older using the Canadian Longitudinal Study on Aging (CLSA). The items making up our FI could be categorised into three domains (physical function, chronic conditions and psychological/cognitive deficits). We further examined if the patterns differed by frailty domain.

METHODS
Study design/setting
The CLSA is one of the largest and most comprehensive research platforms examining health and ageing.24 All study participants provided a core set of information on demographics and measures of lifestyle/behaviour, social, physical, psychological and health status. Of the 51 338 participants, 21 241 were randomly selected from the 10 Canadian provinces and provided questionnaire information through telephone interviews (referred to as CLSA tracking). The other 30 097 (CLSA comprehensive) had in-home interviews to collect information similar to that provided by the CLSA tracking participants and then visited one of 11 Data Collection Sites (DCSs) where they also underwent detailed physical assessments and provided blood and urine samples. Comprehensive participants were randomly selected from areas extending 25–50 km from each of the DCSs. The present analysis uses cross-sectional baseline data from all 51 338 CLSA participants. These data were collected between September 2011 and May 2014 for tracking and between May 2012 and May 2015 for comprehensive participants.

Participants
CLSA participants are community-living women and men aged 45–85 years at the time of recruitment. People who were living on federal First Nations reserves, full-time members of the Canadian Armed Forces, resided in institutions (eg, long-term care institutions), unable to respond in English or French or with cognitive impairment were excluded.

Variables
Frailty Index
The FI used in this study was constructed using the methodology described by Searle et al.25 Details on its construction have been provided elsewhere.26 In brief, each health deficit was recoded as ‘0’ if absent and ‘1’ if present. For non-binary variables, a gradient from 0 to 1 was created using equal steps (eg, if a deficit had three levels, it would be coded ‘0’, ‘0.5’ and ‘1’). The FI value for a participant was the sum of deficits present divided by the total number of deficits measured. Candidate deficits for the FI were selected based on the literature and expert input.25 Deficits were operationalised where possible using the same variables in both the tracking and comprehensive cohorts. An exception was physical functioning measures that were self-reported in the tracking cohort and performance-based in the comprehensive cohort. In previous research we have found that the magnitude of association with disability was similar across self-reported and performance-based measures.26 As well, the relationship between FIs and adverse health outcomes have been
shown to be consistent regardless of the actual variables included if at least 30–40 health deficits are selected using Searle’s criteria. In total, 85 deficits comprised the FI for tracking and 76 for comprehensive participants (71 in common). The items making up the CLSA FI were grouped into three domains: chronic conditions (n=32), psychological function and cognition (n=20) and physical functioning (n=33 for the tracking and n=24 for the comprehensive participants). The creation of the three domains was informed by factor analysis and expert input. A summary of the operationalisation and descriptive statistics for each deficit overall and by cohort is in online supplemental eTable 1.

Social stratifiers
The United Nations 2030 Agenda for Sustainable Development describes the importance of addressing social determinants of health. In this study we used social stratifiers identified by the Pan-Canadian Health Inequalities Reporting Initiative, reflecting key health inequalities in Canada. These included age, sex, income, education, retirement status, rural/urban status and material and social deprivation. Evidence suggests that health deficit accumulation is associated with higher mortality and health service even in middle age. In our study age was categorised as 45–54, 55–64, 65–74 and 75–85 years. Household income per annum was based on Canadian dollars and categorised as <$C20 000, $C20 000–$C50 000, $C50 000–$C100 000, $C100 000–$C150 000 and ≥$C150 000. Education was categorised into not graduating from a secondary school, secondary school graduation with no post-secondary education, some post-secondary education and post-secondary degree or diploma. Retirement was categorised as completed, partly retired and not retired. Rurality was classified by population density into census metropolitan areas (CMA) with a population of 2 million or more (large CMA), CMA’s with population <2 million (other CMA) other smaller towns with population typically 10 000–120 000 (agglomeration) and areas with a population <10 000 (rural). Material and social deprivation quintiles were based on Canadian Census enumeration area data linked to CLSA by the Canadian Urban Environmental Health Research Consortium. Both are small-area based composite indices which reflect the deprivation of relationships among individuals in the family, the workplace and the community (social deprivation) and the deprivation of wealth, goods and conveniences (material deprivation). We did not include the following social stratifiers due to small cell sizes (cultural/racial background, immigration, visible minority and indigenous identity) and occupation type was not yet available.

Covariates
Covariates considered for adjustment were chosen based on the frailty literature. The following covariates were used for adjustment: marital status (married/common-law or other); smoking status (current/former daily smoker or other); nutritional risk (score <38 on AB SCREEN II Nutritional Risk); low self-perceived social participation (yes or no); living alone (yes or no); and low physical activity (<75 min per week of vigorous-intensity or 150 min per week of combined moderate-intensity and vigorous-intensity physical activity. Statistical methods
Descriptive statistics were calculated as means and SD for continuous measures and percentages for categorical variables. In our analyses ‘heterogeneities’ refers to differences in aggregate measures of FI among population groups. The average frailty level and 95% CI were estimated for population subgroups based on social stratifiers using least squares means from linear regression. Frailty estimates were also adjusted for potential confounders and all other social stratifiers. The relative amount of heterogeneity in the FI explained by different social stratifiers was assessed using the LMG statistic. This statistic represents the relative contribution of each variable to the model $R^2$. Analyses were further stratified by sex and age to examine if associations with social stratifiers were consistent or differed by these factors. While we found frailty was higher among women, the patterns across age-groups were similar for women and men and thus they were combined.

Inter-correlations were explored among domain-specific FIs (chronic conditions, physical function, psychological/cognitive). Because income was found to explain the most heterogeneity in the FI among the social stratifiers, the domain-specific regression analyses were restricted to income only. Regression analyses were adjusted for all potential confounders included in the overall frailty model and a final ‘fully adjusted’ model also included the other frailty domains. The CLSA has a complex sampling design, thus weights were calculated to create prevalence estimates that can be generalised to the Canadian population (inflation weights) and for estimating associations (analytical weights). Although the amount of missing data was relatively low, <6.5% for all variables, we anticipated that participants who were frailer might have more missing data. Multiple imputation was conducted using predictive mean matching to provide estimates little prone to bias. The results reflect the average frailty values calculated in 10 imputed data sets and combined. Residual analyses were conducted to assess model fit and appropriateness of underlying assumptions.

Sensitivity analyses included a complete case analysis and separate analyses for tracking and comprehensive cohorts. Because the FI tends to be right-skewed we conducted sensitivity analyses using the natural log of FI ($\ln(\text{FI})$). Finally, more psychological/cognitive and physical functioning deficits had multiple categories (ie, were not binary) and used gradient coding. We conducted sensitivity analyses in which we forced a binary coding for all deficits to assess if higher FI values for these domains could be due to end-aversion bias. All analyses were conducted using analytical weights.
conducted using SAS V.9.4.41 We used the Strengthening the Reporting of Observational Studies in Epidemiology cross-sectional checklist when writing our report.42

Patient and public involvement
There were no participants involved in the development of this study. The results of the CLSA are disseminated to the public through websites and webinars.

RESULTS

Participants
Table 1 displays the characteristics of the CLSA population by age group. The mean FI was 0.131 for all participants and increased with age, from 0.114 for those 45–54 to 0.157 in those 75–85. The psychological/cognition domain had the highest mean values for all subgroups and showed less of an age gradient. Approximately 51% of CLSA participants were women, about 31% had an income less than $C50 000 and most had a post-secondary degree or diploma. About 56% of participants were either completely or partially retired and relatively few lived in a rural area.

Frailty levels across subgroups
Figure 1a displays the average unadjusted FI across population characteristics for each social stratifier except for rural/urban status there was a gradient of higher frailty associated with lower SES. The most heterogeneity in FI was explained by income (R²=13.3%) where the average FI for people making $C150 000 or more was less than half (0.088) of those making less than $C20 000 (0.201). Figure 1b shows the average FI across population characteristics adjusting for potential confounders and all other social stratifiers described above. In the fully adjusted model 24.3% of the variance in FI was explained by all social stratifiers and potential confounders. While SES gradients were attenuated by this adjustment across all subgroups, the heterogeneity across income groups was still apparent after adjusting for all potential confounders explaining 25.6% of the total model R² (24.3%); the other social stratifiers explained between 8.2% (retirement status) to 0.5% (rurality) of the total model R². In total after adjusting for marital status, social participation, living alone, smoking, physical activity and nutritional risk, the social stratifiers still explained 43.3% of the R². Similar results were found when using In(FI) (data not shown). Because fit statistics were similar across models, we chose to present only FI results as they are more easily interpreted than In(FI).

Frailty levels by income level stratified by age and sex
Figure 2 displays the income gradient from the fully adjusted model stratified by age group. While the income gradient was evident for all age groups, the amount of variability in FI explained by all variables in the model (R²) and the relative importance of income (LMG) decreased with age. The model R² ranged from 29.5% (LMG 32.6%) for 45–54 years to 18.2% (LMG 13.3%) for 75–85 years. Women tended to have higher FIs than men overall, but a similar pattern between frailty level, age and income was found across sexes (online supplemental eFigures 1-2).

Domains of frailty
All domains of frailty were weakly to moderately correlated (psychological/cognition and chronic conditions (r=0.29), psychological/cognition and chronic conditions (r=0.39) and physical function and chronic conditions (r=0.46). Figures 3a-c display the income gradient for each domain of frailty–chronic conditions (3a); physical functioning (3b); and, psychological/cognition (3c) by age group. After adjustment for all other factors, including the other frailty domains, there was little income gradient for the chronic conditions domain, but there was a clear gradient of increasing deficits with age. The physical functioning domain had a similar pattern as the overall FI, with a consistent income gradient and the heterogeneity across income groups decreasing with age. The psychological/cognition domain had the strongest income gradient for all age groups, with less heterogeneity with increasing age. The average adjusted psychological/cognition domain score for 45–54 year olds with a household income <$C20 000 was approximately 0.2, representing an endorsement of 20% of the deficits on average. Similar results were found in the complete case analyses and cohort-specific analyses (data not shown).

DISCUSSION

Identifying how frailty levels vary across social stratifiers associated with health inequalities, and examining whether the associations found, differ across age groups can help guide public health interventions as there has been much focus on proximal causes and less of ‘fundamental causes’ associated with socioeconomic inequalities.12 Other than urban/rural status we found that mean FI values were associated with all the social stratifiers suggested by the Pan-Canadian Health Inequities Reporting Initiative28 that we could assess. This persisted after adjustment for potential confounders and other social stratifiers. The frailty gap across income groups was greatest in the younger age groups compared with those 65 years and older. In fact, we found the average frailty level for 45–54 year olds in the lowest income group is greater than that for 75–85 year olds in our study population. Furthermore, especially in the younger age groups, the heterogeneity among income groups was associated primarily with the psychological/cognitive deficits used to calculate the FI. While frailty levels were higher among women compared with men, the patterns across age groups and income were similar.

Our results agree with many studies examining the association between social determinants of health and
Table 1  Frailty level and demographic, socioeconomic and lifestyle characteristics for all participants of the Canadian Longitudinal Study on Aging (n=51 338) and by 10-year age groups

| Variable                                | All ages | 45–54 | 55–64 | 65–74 | 75–85 |
|-----------------------------------------|----------|--------|--------|--------|--------|
|                                         | Mean     | SD     | Mean   | SD     | Mean   | SD     | Mean   | SD     | Mean   | SD     |
| Frailty Index                           | 0.131    | 0.076  | 0.114  | 0.071  | 0.126  | 0.076  | 0.136  | 0.074  | 0.157  | 0.077  |
| Chronic condition subdomain             | 0.110    | 0.082  | 0.074  | 0.066  | 0.100  | 0.076  | 0.127  | 0.081  | 0.156  | 0.085  |
| Physical subdomain                      | 0.109    | 0.095  | 0.094  | 0.086  | 0.106  | 0.092  | 0.111  | 0.093  | 0.133  | 0.108  |
| Psychological/cognitive subdomain       | 0.196    | 0.131  | 0.205  | 0.138  | 0.197  | 0.137  | 0.184  | 0.124  | 0.194  | 0.118  |

| Variable                                | Category                          | N     | %    | N     | %    | N     | %    | N     | %    |
|-----------------------------------------|-----------------------------------|-------|------|-------|------|-------|------|-------|------|
| Sex                                     | Male                              | 25 183| 49.05| 6486  | 48.31| 7955  | 48.45| 5968  | 49.75|
|                                        | Female                            | 26 155| 50.95| 6941  | 51.69| 8465  | 51.55| 6028  | 50.25|
| Income                                  | Less than $C20 000                | 3224  | 6.28 | 536   | 3.99 | 916   | 5.58 | 863   | 7.19 |
|                                        | $C20 000 or more, but less than $C50 000 | 13 393| 26.09| 1659  | 12.36| 3508  | 21.36| 4156  | 34.64|
|                                        | $C50 000 or more, but less than $C100 000 | 18 256| 35.56| 4138  | 30.82| 6105  | 37.18| 4741  | 39.52|
|                                        | $C100 000 or more, but less than $C150 000 | 9131 | 17.79| 3565  | 26.55| 3249  | 19.79| 1455  | 12.13|
|                                        | $C150 000 or more                 | 7334  | 14.29| 3529  | 26.28| 2642  | 16.09| 781   | 6.51 |
| Education                               | Less than secondary school graduation | 3644 | 7.10 | 427   | 3.18 | 751   | 4.57 | 1013  | 8.44 |
|                                        | Secondary school graduation, no post-secondary education | 5743 | 11.19| 1253  | 9.33 | 1880  | 11.45| 1417  | 11.81|
|                                        | Some post-secondary education      | 3874  | 7.55 | 807   | 6.01 | 1306  | 7.95 | 918   | 7.65 |
|                                        | Post-secondary degree/diploma      | 38 077| 74.17| 10 940| 81.48| 12 483| 76.02| 8648  | 72.09|
| Retirement                              | Completely retired                | 23 364| 45.51| 608   | 4.53 | 5691  | 34.66| 8695  | 72.48|
|                                        | Partly retired                     | 5588  | 10.88| 446   | 3.32 | 2519  | 15.34| 1954  | 16.29|
|                                        | Not retired                        | 22 386| 43.61| 12 373| 92.15| 8210  | 50   | 1347  | 11.23|
| Urban/rural status                      | Rural                             | 6995  | 13.63| 1904  | 14.18| 2209  | 13.45| 1608  | 13.40|
|                                        | Agglomeration                      | 4561  | 8.88 | 1207  | 8.99 | 1401  | 8.53 | 1035  | 8.63 |
|                                        | Other CMA                          | 30 514| 59.44| 7815  | 58.20| 9874  | 60.13| 7242  | 60.37|
|                                        | Large CMA                          | 9268  | 18.05| 2501  | 18.63| 2936  | 17.88| 2111  | 17.60|
| Married                                 | No                                 | 16 076| 31.31| 3250  | 24.20| 4623  | 28.15| 3905  | 32.55|
|                                        | Yes                                | 35 262| 68.69| 10 177| 75.80| 11 797| 71.85| 8091  | 67.45|
| Smoke                                   | No                                 | 26 279| 51.19| 7756  | 57.76| 8103  | 49.35| 5726  | 47.73|
|                                        | Yes                                | 25 059| 48.81| 5671  | 42.24| 8317  | 50.65| 6270  | 52.27|
| Nutritional risk                        | No                                 | 42 957| 83.67| 11 132| 82.91| 13 724| 83.59| 10 258| 85.51|
|                                        | Yes                                | 8381  | 16.33| 2295  | 17.09| 2696  | 16.42| 1738  | 14.49|

Continued
## Table 1 Continued

| Variable                        | Category          | N     | %    | N     | %    | N     | %    | N     | %    |
|---------------------------------|-------------------|-------|------|-------|------|-------|------|-------|------|
| Low social participation        | No                | 28722 | 55.95| 6176  | 46   | 8630  | 52.56| 7562  | 63.04| 6354  | 66.92|
|                                 | Yes               | 22616 | 44.05| 7251  | 54   | 7790  | 47.44| 4434  | 36.96| 3141  | 33.08|
| Live alone                      | No                | 39591 | 77.12| 11885 | 88.52| 13171 | 80.21| 8758  | 73.01| 5777  | 60.84|
|                                 | Yes               | 11747 | 22.88| 1542  | 11.48| 3249  | 19.79| 3238  | 26.99| 3718  | 39.16|
| Material Deprivation Factor     | 1 (low)           | 10275 | 20.01| 2441  | 18.18| 3209  | 19.54| 2514  | 20.96| 2111  | 22.23|
| Index Factor Score Quintile     | 2                 | 10279 | 20.02| 2708  | 20.17| 3362  | 20.48| 2385  | 19.88| 1824  | 19.21|
|                                 | 3                 | 10259 | 19.98| 2781  | 20.71| 3341  | 20.35| 2336  | 19.47| 1801  | 18.97|
|                                 | 4                 | 10246 | 19.96| 2768  | 20.62| 3234  | 19.70| 2335  | 19.46| 1909  | 20.11|
|                                 | 5 (high)          | 10279 | 20.02| 2729  | 20.32| 3274  | 19.94| 2426  | 20.22| 1850  | 19.48|
| Social Deprivation Factor       | 1 (low)           | 10262 | 19.99| 2909  | 21.67| 3451  | 21.02| 2350  | 19.59| 1552  | 16.35|
| Index Factor Score Quintile     | 2                 | 10274 | 20.01| 2784  | 20.73| 3281  | 19.98| 2426  | 20.22| 1783  | 18.78|
|                                 | 3                 | 10247 | 19.96| 2774  | 20.66| 3263  | 19.87| 2366  | 19.72| 1844  | 19.42|
|                                 | 4                 | 10266 | 20    | 2619  | 19.51| 3338  | 20.33| 2335  | 19.46| 1974  | 20.79|
|                                 | 5 (high)          | 10289 | 20.04| 2341  | 17.44| 3087  | 18.80| 2519  | 21   | 2342  | 24.67|
| Low physical activity           | No                | 15480 | 30.15| 5103  | 38.01| 5290  | 32.22| 3283  | 27.37| 1804  | 19    |
|                                 | Yes               | 35858 | 69.85| 8324  | 61.99| 11130 | 67.78| 8713  | 72.63| 7691  | 81    |

CMA, census metropolitan area; .
frailty,43–46 frailty trajectories17 18 and the rate of deficit accumulation.19 47 48 Hajizadeh et al49 found persistent education-related and income-related inequalities in frailty were present in all regions of Canada. St John et al46 reported there was a gradient in frailty across several measures of social position (education, income security, home ownership and satisfaction with income). We found that household income had the strongest relationship with frailty heterogeneity both in an unadjusted analysis and in an analysis adjusted for all other social stratifiers assessed. The fully adjusted model included all social stratifiers shown in the Figure, as well as potential confounding variables: marital status (married/common-law or other); smoking status (current/former daily smoker or other); nutritional risk (score <38 on AB SCREEN II Nutritional Risk)34; low self-perceived social participation (yes or no); living alone (yes or no); and low physical activity (<75 min per week of vigorous-intensity or 150 min per week of combined moderate-intensity and vigorous-intensity physical activity. Points show the least-squared mean FI. CMA, census metropolitan area; LS, least square.

Figure 1  (A) shows the unadjusted weighted least squares mean Frailty Index (FI), 95% CI and the associated model R² for each social stratifier assessed. (B) shows the fully adjusted weighted least squares mean frailty and 95% CI by social stratifier. The variance in FI explained by all variables was R²=24.3%; the LMG represents the per cent of the model R² explained by each social stratifiers assessed. The fully adjusted model included all social stratifiers shown in the Figure, as well as potential confounding variables: marital status (married/common-law or other); smoking status (current/former daily smoker or other); nutritional risk (score <38 on AB SCREEN II Nutritional Risk)34; low self-perceived social participation (yes or no); living alone (yes or no); and low physical activity (<75 min per week of vigorous-intensity or 150 min per week of combined moderate-intensity and vigorous-intensity physical activity. Points show the least-squared mean FI. CMA, census metropolitan area; LS, least square.
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Figure 2 shows the adjusted weighted least squares mean Frailty Index and 95% CI for each level of income, by 10-year age categories and adjusted for all other social stratifiers (education, geography, retirement status, material and social deprivation indices), as well as potential confounding variables: marital status (married/common-law or other); smoking status (current/former daily smoker or other); nutritional risk (score <38 on AB SCREEN II Nutritional Risk); low self-perceived social participation (yes or no); living alone (yes or no); and low physical activity (<75 min per week of vigorous-intensity or 150 min per week of combined moderate-intensity and vigorous-intensity physical activity). $R^2$ represents the proportion of variance in Frailty Index explained by all variables each model (one for each age group); LMG represents the proportion of the model variance explained ($R^2$) that can be attributed to household income.

(physical functioning subscale) and subjective health (self-perceived health). They found that after controlling for confounders, income was significantly related to functional and subjective health but not to physical health based on the number of chronic conditions. They further found that the interaction between income and age was not significant for physical and functional health, but was significant for subjective health, due to the decreased influence of low income on subjective health at older ages. Kim and Durden examined SES indicators and physical impairment and depression and found that income-based gradients in physical impairment grew over time for all adult age groups while the one with depression converged at older ages. Franse et al examined the association between frailty domains and SES (education) and found that among all frailty components other than instrumental activities of daily living stronger associations were observed in persons 55–69 years (their youngest age group) compared with older age groups. The strongest association was found with psychosocial health. Interestingly, of the literature we reviewed examining health inequalities and frailty level, the per cent of psychological health/cognitive deficits was less than 10% in five studies, between 10%–25% in one study, and

Figure 3 (A-C) shows the adjusted weighted least squares mean domain-specific Frailty Index and 95% CI by level of household income and stratified by age group. (A) represents the chronic conditions domain, (B) physical domain and (C) psychological/cognitive domain. Each model is adjusted for the other domains of frailty, all other social determinants (education, geography, retirement, material and social deprivation indices), as well as potential confounding variables: marital status (married/common-law or other); smoking status (current/former daily smoker or other); nutritional risk (score <38 on AB SCREEN II Nutritional Risk); low self-perceived social participation (yes or no); living alone (yes or no); and low physical activity (<75 min per week of vigorous-intensity or 150 min per week of combined moderate-intensity and vigorous-intensity physical activity). $R^2$ represents the proportion of variance in the domain-specific Frailty Index explained by all variables each model (one for each age group); LMG represents the proportion of the model variance explained ($R^2$) that can be attributed to household income.
>25% in three. Particularly when studies include younger participants it may be important to include more psychological items in the assessment of frailty.

This study used data from a large population-based study including middle-aged and older adults. The richness of the data and the magnitude of the sample size allowed us to examine many social stratifiers and adjust for numerous potential confounders. The sample size also allowed us to conduct stratified analyses to examine these relationships by policy-relevant subgroups (age and sex) that can be used to inform further research, policy and the development of potential interventions. We also conducted numerous sensitivity analyses to assess the robustness of our results to methodological decisions made throughout our study. Compared with other FLs creating from CLSA, our mean FI values tended to be slightly higher. This is most likely due to our inclusion of relatively more psychological/cognition deficits which were of a priori interest. This study, however, as with others also has limitations. Sampling bias may be present, as participants were generally healthy volunteers residing in the community. For many variables CLSA results have been shown to be similar to other population-based Canadian data sources, but CLSA participants tended to be more highly educated, have higher household income, have higher percentages of participants who are Canadian born. It should be noted that were not able to examine cultural/racial background, immigration, visible minority and indigenous identity in this study. We know that frailty prevalence and trajectories vary between ethnic groups, migrants and minority native groups. While our results may not be completely representative, the level of heterogeneity in frailty level among income groups that we found would likely be an underestimate. The data presented are also cross-sectional. We are not able to rule out reverse causation or disentangle potential cohort effects. It is possible that an increase in one’s level of frailty could affect their ability to work and thus lead to reduced income. Other longitudinal studies have also found income gradients with respect to frailty, though not all. Previous studies have also shown that there are cohort differences in frailty levels possibly attributable to differential survival of frail individuals.

**Clinical and public health importance**

Reducing frailty and its negative health consequences is a priority for public health. Our results suggest that especially in the younger age groups, psychological/cognitive deficits are most highly associated with both overall frailty levels and the gradient in frailty associated with income. If this is predictive of later increases in the other two domains (and overall frailty), it raises the question whether targeting mental health factors earlier in life might be an effective approach to mitigating frailty. Longitudinal data are needed to explore both the time course and inter-relationships across the three domains. In particular, research is needed to examine how the FI domains evolve over time and how well this evolution predicts adverse outcomes.

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**Contributors**

LEG and PR designed the project with the input from all authors. All authors (LEG, PR, DK, DH, CP, AP, JR, AG, MT and EvdH) worked together to obtain funding for and deciding the scope and structure of the study. DK conducted all analyses with statistical input from MT and EvdH. LEG wrote the first draft of the manuscript. All authors (LEG, PR, DK, DH, CP, AP, JR, AG, MT and EvdH) contributed to the interpretation, writing and critical revision of the manuscript and approved the final manuscript.

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**Competing interests**

None declared.

**Patient consent for publication**

Obtained.

**Ethics approval**

This study was approved by the Hamilton Integrated Research Ethics Board (Ethics certificate #: 3152). Participants of the Canadian Longitudinal Study on Aging provided written informed consent to participate.

**Provenance and peer review**

Not commissioned; externally peer reviewed.

**Data availability statement**

Data are available upon reasonable request. Data are available from the Canadian Longitudinal Study on Aging (www.clsa-elcv.ca) for researchers who meet the criteria for access to de-identified CLSA data.

**Supplemental material**

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REFERENCES
1. Griffith LE. frailty syndrome: definition and natural history. Clin Geriatr Med 2011;27:1-15.
2. Kojima G. Frailty as a predictor of disabilities among community-dwelling older people: a systematic review and meta-analysis. Disabil Rehabil 2017;39:1897-908.
3. Kojima G. Frailty as a predictor of fractures among community-dwelling older people: a systematic review and meta-analysis. Bone 2016;90:116-22.
4. Kojima G, Iliiffe S, Walters K. Frailty index as a predictor of mortality: a systematic review and meta-analysis. Age Ageing 2014;43:179-200.
5. Kojima G. Increased healthcare costs associated with frailty among community-dwelling older people: a systematic review and meta-analysis. Arch Gerontol Geriatr 2019;84:103898–103.
6. Butler A, Gallagher D, Gillespie P, et al. Frailty: a costly phenomenon in caring for elders with cognitive impairment. Int J Geriatr Psychiatry 2016;31:161–8.
7. Cesari M, Prince M, Thiyyagaran JA, et al. Frailty: an emerging public health priority. J Am Med Dir Assoc 2016;17:188–92.
8. Hoogendijk EO, Alfalfo J, Ensrud KE, et al. Frailty: implications for clinical practice and public health. Lancet 2019;394:1385–75.
9. Braveman P, Gottlieb L. The social determinants of health: it’s time to consider the causes of the causes. Public Health Rep 2014;129 Suppl 2:19–31.
10. Wickrama KKAS, Mancini JA, Kwag K, et al. Heterogeneity in multidimensional health trajectories of late old years and socioeconomic stratification: a latent trajectory class analysis. J Gerontol B Psychol Sci Soc Sci 2013;68:290–7.
11. Schöllgen I, Huxhold O, Tesch-Römer C. Socioeconomic status and health: the first half of life: findings from the German ageing survey. Eur J Ageing 2010;7:17–28.
12. Link BG, Phelan J. Social conditions as fundamental causes of disease. J Health Soc Behav 1995;Spec No:80–94.
13. Leopold L, Engelhardt H. Ermutat zu: education and physical health trajectories in old age. Evidence from the survey of health, ageing and retirement in Europe (SHARE), Int J Public Health 2013;58:329–31.
14. Schöllgen I, Huxhold O, Schmiedek F. Emotions and physical health in the second half of life: interindividual differences in age-related trajectories and dynamic associations according to socioeconomic status. Psychiatr Q 2017;88:725–38.
15. Benzeval M, Green MJ, Leyland AH. Do social inequalities in health widen or converge with age? longitudinal evidence from three cohorts in the West of Scotland. BMC Public Health 2011;11.
16. Lynch SM. Cohort and life-course patterns in the relationship between education and health: a hierarchical approach. Demography 2003;40:309–31.
17. Hoogendijk EO, Rijnhart JJM, Kowal P, et al. Socioeconomic inequalities in frailty among older adults in six low- and middle-income countries: results from the who study on global ageing and adult health (SAGE). Maturitas 2018;115:56–63.
18. Stolz E, Mayeri H, Wexenenegger A, et al. Impact of socioeconomic position on frailty trajectories in 10 European countries: evidence from the survey of health, ageing and retirement in Europe (SHARE). J Epidemiol Community Health 2013;67:73–80.
19. Marshall A, Nazroo J, Tampubolon G, et al. Cohort differences in the levels and trajectories of frailty among older people in England. J Epidemiol Community Health 2015;69:316–21.
20. Kim J, Durden E. Socioeconomic status and age trajectories of health. Soc Sci Med 2007;65:2489–502.
21. Searle SD, Mitnitski A, Gahbauer EA, et al. A standard procedure for creating a frailty index. BMC Geriatr 2008;8:24.
22. Hertzman C, Frank J, Evans RG. Heterogeneities in health status and the determinants of population health. in: Evans RG, Barer ml, Marmor TR, editors. why are some people healthy and others are not?: the determinants of the health of populations. New York: Aldine de Gruyter, 1994:67–92.
23. Abrams EM, Szefler SJ. COVID-19 and the impact of social determinants of health. Lancet Respir Med 2020;8:659–61.
24. Raina P, Wolfson C, Kirkland S, et al. Cohort profile: the Canadian longitudinal study on aging (CLSA). Int J Epidemiol 2019;48:1752–3.
25. Kanters DM, Griffith LE, Hogan DB, et al. Assessing the measurement properties of a frailty index across the age spectrum in the Canadian longitudinal study on aging. J Epidemiol Community Health 2017;71:794–9.
26. Mayhew AJ, Griffith LE, Gilsing A, et al. The association between self-reported and performance-based physical function with activities of daily living disability in the Canadian longitudinal study on aging. The journals of gerontology Series A, Biological sciences and medical sciences 2019.
27. Marmot M, Allen J, Bell R, et al. Consortium for the European review of social determinants of health and the health divide. who European review of social determinants of health and the health divide. Lancet 2012;380:1011–29.
28. Public Health Agency of Canada. Pan-Canadian health inequalities reporting initiative. Key health inequalities in Canada: a national portrait. HP2-10/2014E, Ottawa, Canada: Public Health Agency of Canada, 2018.
29. Rockwood K, Song X, Mitnitski A. Changes in relative fitness and frailty across the adult lifespan: evidence from the Canadian population health survey. J Gerontol B Psychol Sci Soc Sci 2007;62B:S27–33.
30. Statistics Canada. Census metropolitan area (CMA) and census agglomeration (Ca). 92-195-X, 2017. Ottawa, Canada, statistics Canada. Available: https://www150.statcan.gc.ca/n1/pub/92-195-x/2016001/geo/cma-cma-eng.htm
31. Rampaloon R, Hamel D, Gacache P, et al. A deprivation index for health planning in Canada. Chronic Dis Can 2009:29:178–91.
32. Brook JR, Setton EM, Seed E, et al. The Canadian Urban Environmental Health Research Consortium - a protocol for building a national environmental exposure data platform for integrated analyses of urban form and health. BMC Public Health 2018;18:114.
33. Chamberlain AM, St Sauver JL, Jacobson DJ, et al. Social and behavioural factors associated with frailty trajectories in a population-based cohort of older adults. BMJ Open 2016;6:e011410.
34. Verlaan S, Ligthart-Melis GC, Wijers SLJ, et al. High prevalence of physical frailty among community-dwelling malnourished older Adults-A systematic review and meta-analysis. J Am Med Dir Assoc 2017;18:374–82.
35. Keller HH, Goy R, Kane S-L. Validity and reliability of screen II (seniors in the community: risk evaluation for eating and vitamin, version II). Eur J Clin Nutr 2005;59:1149–57.
36. World Health Organization. Global recommendations on physical activity for health. World Health Organization, 2020.
37. Kruskal W. Relative importance by averaging over orderings. Amer Statist 1967;11:5–10.
38. CLSA Methodology Working Group. CLSA technical document: sampling and computation of response rates and sample weights for the tracking (telephone interview) participants and comprehensive participants, v1.1, 2017. Hamilton, Ontario.
39. Regeurregner N, Verduaux H, Giorgi R, et al. Dealing with missing data in the center for epidemiologic studies depression self-report scale: a study based on the French E3N cohort. BMC Med Res Methodol 2013;13:28.
40. David LS, Geoffrey RN, John C. Health measurement scales. A practical guide to their development and use. Oxford, UK: Oxford University Press, 2014.
41. SAS/STAT software. SAS Institute Inc Cary, NC., 2017.
42. von Elm E, Altman DG, Egger M, et al. Strengthening the reporting of observational health survey. CMAJ 2011;1;183:E67–94.
43. Romero-Ortuno R. Frailty index in Europeans: association with determinants of health. Geriatr Gerontol Int 2014;14:420–9.
44. Harttgen K, Kowal P, Strulik H, et al. Patterns of frailty in older adults: comparing results from higher and lower income countries using the survey of health, ageing and retirement in Europe (share) and the study on global ageing and adult health (SAGE). PLoS One 2013;8:e75847.
45. Franse CB, van Grieken A, Qin L, et al. Socioeconomic inequalities in frailty and frailty components among community-dwelling older citizens. PLOS One 2017;12:e0187946.
46. St John PD, Montgomery PR, Tyas SL. Social position and frailty. Can J Aging 2013;32:250–9.
47. Stephan AJ-R, Strobl R, Holle R, et al. Wealth and occupation determine health deficit accumulation onset in Europe - Results from the SHARE study. Exp Gerontol 2018;113:74–9.
48. Yang Y, Lee LC. Dynamics and heterogeneity in the process of human frailty and aging: evidence from the U.S. older adult population. J Gerontol B Psychol Sci Soc Sci 2010;65:246–55.
49. Haszprunar R, Mitnitski A, Rockwood K. Socioeconomic gradient in health in Canada: is the gap widening or narrowing? Health Policy 2016;120:1040–50.
50 House JS, Lantz PM, Herd P. Continuity and change in the social stratification of aging and health over the life course: evidence from a nationally representative longitudinal study from 1986 to 2001/2002 (Americans’ changing lives study). J Gerontol B Psychol Sci Soc Sci 2005;60 Spec No 2:S15–26.

51 Government of Canada. Old age security - eligibility. Available: ca/en/services/benefits/publicpensions/cpp/old-age-security/eligibility.html [Accessed 06 Oct 2020].

52 Nguyen QD, Moodie EM, Forget M-F, et al. Health heterogeneity in older adults: exploration in the Canadian longitudinal study on aging. J Am Geriatr Soc 2021;69:678–87.

53 Chamberlain AM, Finney Rutten LJ, Manemann SM, et al. Frailty trajectories in an elderly population-based cohort. J Am Geriatr Soc 2016;64:285–92.

54 Pérez-Zepeda MU, Godin J, Armstrong JJ, et al. Frailty among middle-aged and older Canadians: population norms for the frailty index using the Canadian longitudinal study on aging. Age Ageing 2021;50:447–56.

55 Majid Z, Welch C, Davies J, et al. Global frailty: the role of ethnicity, migration and socioeconomic factors. Maturitas 2020;139:33–41.