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MORTALITY

Life expectancy gap between the Francophone majority and Anglophone minority of a Canadian population

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Abstract Language is an important determinant of health, but analyses of linguistic inequalities in mortality are scant, especially for Canadian linguistic groups with European roots. We evaluated the life expectancy gap between the Francophone majority and Anglophone minority of Québec, Canada, both over time and across major provincial areas. Arriaga's method was used to estimate the age and cause of death groups contributing to changes in the life expectancy gap at birth between 1989–1993 and 2002–2006, and to evaluate patterns across major provincial areas (metropolitan Montréal, other metropolitan centres, and small cities/rural areas). Life expectancy at birth was greater for Anglophones, but the gap decreased over time by 1.3 years (52% decline) in men and 0.9 years (47% decline) in women, due to relatively sharper reductions in Francophone mortality from several causes, except lung cancer which countered reductions in women. The life expectancy gap in 2002–2006 was widest in other metropolitan centres (men 5.1 years, women 3.2 years), narrowest in small cities/rural areas (men 0.8 years, women 0.7 years), and tobacco-related causes were the main contributors. Only young Anglophones <40 years in small cities/rural areas had mortality higher than Francophones, resulting in a narrower gap in these areas. Differentials in life expectancy favouring Anglophones decreased over time, but varied across areas of Québec. Tobacco-related causes accounted for the majority of the current life expectancy gap.

Keywords Language · Life expectancy · Mortality · Smoking · Tobacco · Trends

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Introduction

Social factors such as race and ethnicity, socioeconomic position, and gender are associated with health in most countries [1–3]. However, few studies have considered linguistic status a route through which health inequalities may manifest, despite evidence that language may be an important determinant of health [4–6]. Fluency in the official language of a country may determine accessibility to health care and contribute to sense of belonging or social status, which may influence more proximal determinants such as health behaviours or other risk factors for mortality [7]. Educational or other socioeconomic opportunities such as employment may be greater for individuals who speak their country's dominant language.

Inequalities in mortality may also vary over time and place for different social groups [8, 9]. Research has demonstrated persistent language-based inequalities across areas of Finland [10–12]. Whether language-based differences exist for other countries is unclear, even in places where several linguistic groups are dominant. Of particular interest are the Francophone and Anglophone populations in the province of Québec, Canada. French is the majority language in Québec, with English second most commonly spoken [13]. A long history of juxtaposed cultures and linguistic tensions exists for Francophones and Anglophones in Québec, dating back to the European colonization of North America [14]. Health-related behaviours differ between these groups, including tobacco or alcohol consumption [7, 15]. Francophones in Québec were historically more prevalent in lower social classes compared with Anglophones, but no research has evaluated mortality between these two groups [13, 14, 16].

To evaluate potential linguistic inequalities in mortality in Québec, we estimated the life expectancy gap at birth between Francophones and Anglophones, and determined the ages and causes of death contributing to the gap over time and across major areas of Québec. We used Arriaga's demographic method to undertake analyses [17–19], rather than regression-based epidemiologic strategies that instead focus on identification and assessment of risk factors for mortality using measures of association and confidence intervals, which may be less practical for guiding policy. Arriaga's method is increasingly used in epidemiology for its potential to provide useful targets for public health intervention to equalize life expectancy between groups [3, 20–25].

Methods

Data and variables

There were 523,780 deaths in Québec during the two 5-year periods available for analyses (1989–1993 and 2002–2006). Male and female decedents whose language spoken at home was reported as French ($N = 392{,}341$) or English ($N = 50{,}813$) were extracted. Francophone deaths were defined as French or French plus another non-English language spoken at home, and Anglophone deaths as English or English plus another non-French language. Bilingual French–English ($N = 3{,}031$) and foreign languages ($N = 15{,}738$) were not evaluated. The majority of Anglophones in Québec live in Montréal, with fewer in other metropolitan centres or rural areas [26]. As regional concentration of linguistic groups could influence mortality, three areas (metropolitan Montréal, other metropolitan centres, and small cities/rural areas) were assessed for 2002–2006 (data for 1989–1993 were not available). Other metropolitan centres included Québec City, Sherbrooke, Trois-Rivières, Saguenay, and Gatineau.

Language spoken at home was unknown for 11.8% of deaths, and was assumed to be missing at random [27, 28]. These data were imputed [29, 30] based on the distribution of age, sex, country of birth (Québec, other Canadian province, foreign country), quintile of material deprivation [31], and proportion Anglophone deaths in neighbourhoods (small areas containing 500–750 inhabitants on average [32]). As language data are nominal (French, English, bilingual, foreign language), multiple imputation employing the monotone discriminant statement of the MI procedure in SAS was used to generate five imputed datasets, each used to replicate analyses separately five times. After imputation, there were 444,142 Francophone and 56,882 Anglophone deaths on average (the characteristics of unimputed and imputed data were similar).

Provincial population counts were obtained from Statistics Canada for the 1991 and 2006 census years [33]. Population counts for Montréal, other metropolitan centres, and small cities/rural areas were obtained for 2006. Counts were adjusted for under enumeration using age and sex-specific correction factors derived from Institut de la statistique du Québec population estimates [34]. Counts for 2006 were projected to 2004, the central year of 2002–2006. Live birth certificates were used to determine population counts for infants <1 year.

Calculation of life expectancy

Age-specific mortality rates for men and women were calculated for 20 age groups (<1, 1–4, 5–9, 10–14, …, 85–89, 90+ years), and converted to life table probabilities of dying for the estimation of life expectancy at birth in standard life tables [35]. The probability of death under 1 year was calculated from the infant mortality rate [36]. A probability of death equal to 1 was assumed for the 90+ age group [37]. The mean of five imputed life expectancy estimates with 95% confidence intervals adjusted for the added variance due to imputation was computed [30, 35], upon verification that results for each imputation were similar. Life expectancy at birth was calculated for the whole of Québec for both periods and, in 2002–2006, for Montréal, other metropolitan centres, and small cities/rural areas.

Decomposition of life expectancy gap

The absolute difference in life expectancy at birth between Francophones and Anglophones was decomposed into age group and cause of death components for each imputed dataset using Arriaga's method [17, 18]. The mean of the

five decompositions was calculated. Appendix 1 describes Arriaga's method. Statistical significance testing was not undertaken, and future research is necessary to identify methods to do so by this approach. Time trends were evaluated for the whole of Québec, and area-based trends for 2002–2006. Appendix 2 lists the International Classification of Disease (ICD) codes for principal cause of death, defined as the disease or injury that initiated the events directly responsible for death [38], used for population health surveillance provincially [37]. Directly standardized cause-specific mortality rates for the mean of the five imputed datasets were used to interpret results from the Arriaga decomposition (Appendix 3).

Analyses were performed with SAS 9.1 (SAS Institute Inc., Cary, NC). Life expectancy was calculated using an adapted SAS macro [39]. This study conformed to the 2010 Tri-Council Policy Statement for ethical conduct of research on humans in Canada.

Results

The total population in Québec increased from 7.06 million in 1991 to 7.54 million in 2004, at which point 48.3% were in Montréal, 19.6% in other metropolitan centres and 32.1% in small cities/rural areas. In 1991, the population was 82.8% Francophone and 10.9% Anglophone. Though the population increased in all language groups, by 2004 there were proportionately fewer Francophones (81.8%) and Anglophones (10.4%), with a greater proportion of Anglophones in Montréal (17.2%) than other metropolitan centres (4.1%) or small cities/rural areas (3.9%). Sex-based differences in the population distribution were not apparent.

Life expectancy at birth increased for both language groups and sexes over time, and was highest in 2002–2006 for Anglophone men and women (Table 1). In all periods the life expectancy of Francophones was lower than Anglophones. The absolute difference in life expectancy between the two groups, however, narrowed over time by 2.1 years for men and 1.6 years for women (Fig. 1). For men, much of the decrease in the gap was explained by reductions in ischemic heart/cerebrovascular disease, lung cancer, infant mortality, and residual causes that were relatively greater for Francophones than Anglophones. The same causes explained the decrease in the life expectancy gap in women. An important difference in women, however, was that lung cancer countered the decrease due to rising rates that over time were relatively greater for Francophones. With respect to age, reductions in the life expectancy gap were generally due to lower mortality over time in men older than 50 years and women older than 70 years, as well as in infants of both sexes.

Table 1 Life expectancy at birth according to sex and language spoken at home, Québec, 1989–1993 and 2002–2006

	Francophone	Anglophone	Absolute difference[a]
Men			
1989–1993	72.6	77.0	4.4
2002–2006	76.5	78.8	2.3
Women			
1989–1993	80.0	83.0	3.0
2002–2006	81.8	83.2	1.4

Confidence intervals were different at the third (Francophone) or second (Anglophone) decimal position, and are not shown

[a] Absolute difference in life expectancy at birth between Francophones and Anglophones

Figure 1 also demonstrates that, for the whole of Québec, the main causes contributing to the 2.3 year provincial life expectancy gap in 2002–2006 (favouring Anglophone men) were ischemic heart disease (7.8%), lung cancer (24.3%), chronic lower respiratory disease (10.4%), transport injuries (13.5%), suicide (18.7%), and residual causes (10.9%). The same causes explained a large proportion of the 1.4 year provincial gap between Francophone and Anglophone women (proportions differed slightly from men). However, an important contributor in women (but not men) was Alzheimer's disease (8.6%).

From a behavioural viewpoint, tobacco- and alcohol-related causes accounted for the majority of the life expectancy gap in 2002–2006 for both sexes. Tobacco-related causes contributed 1.0 years (45.6%) in men and 0.6 years (43.1%) in women, with alcohol-related causes accounting for an additional 0.8 years (35.8%) in men and 0.3 years (19.4%) in women (data not in table).

Patterns in 2002–2006 were somewhat different across areas (Table 2). Life expectancy was highest in other metropolitan centres for both languages, and favoured Anglophones in all three areas. The Francophone-Anglophone life expectancy gap was greatest in other metropolitan centres (men 5.1 years, women 3.2 years). Small cities/rural areas generally had the lowest life expectancy and narrowest gap.

In Montréal and other metropolitan centres, the causes contributing to the Francophone-Anglophone life expectancy gap were proportionately similar (though the absolute contribution in years differed) (Table 3). An exception was Alzheimer's disease in women, an important contributor in Montréal but not other metropolitan centres. In small cities/rural areas, higher rates of lung cancer (both sexes), transport injuries (men), and cerebrovascular disease/breast cancer (women) among Francophones explained much of the gap. However, higher rates of unintentional injuries (men) and infant mortality (both sexes) in Anglophones offset the gap that would otherwise have been wider.

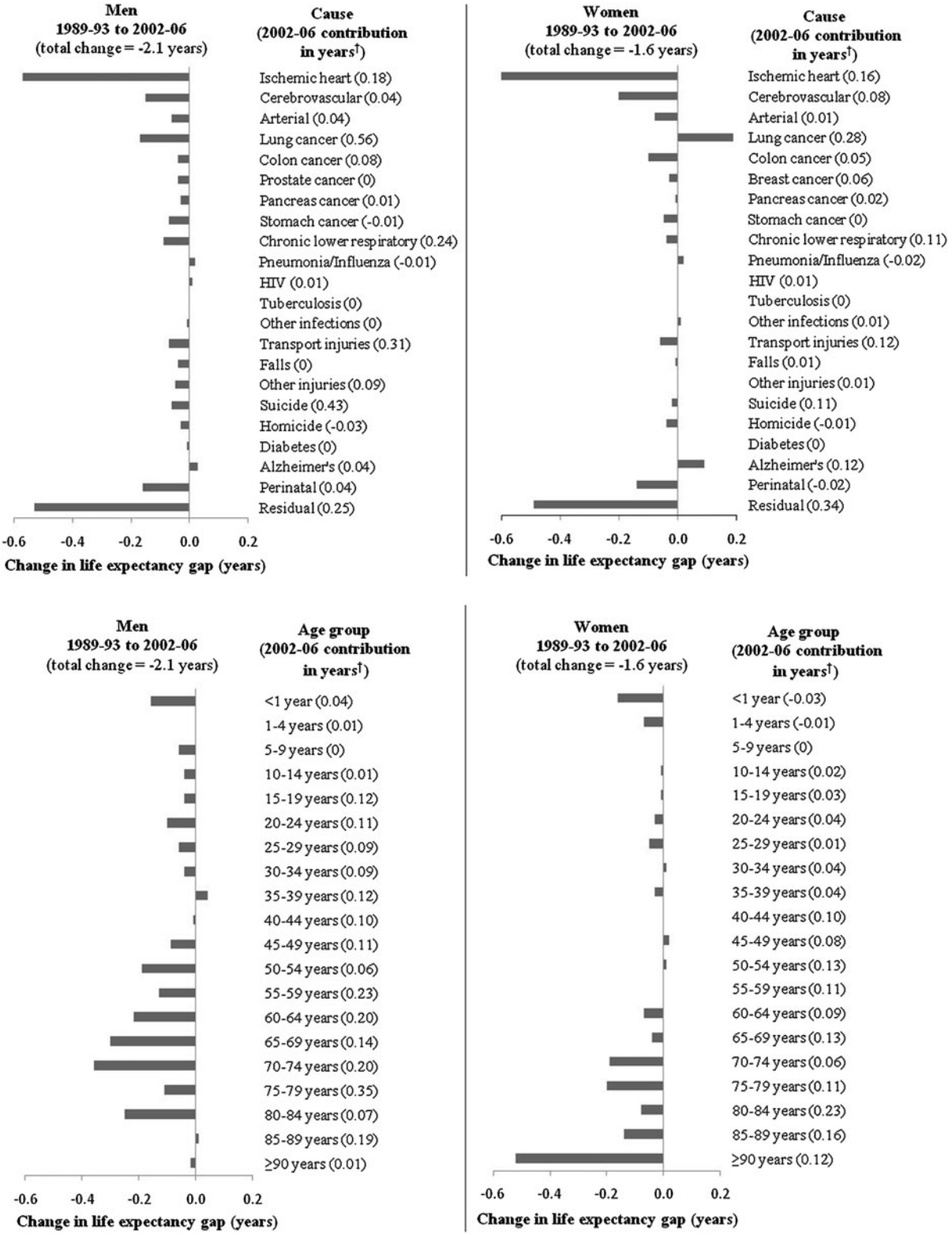

Fig. 1 Age and cause groups contributing to the decrease in the Francophone-Anglophone life expectancy gap at birth from 1989–1993 to 2002–2006, men and women, Québec. *Left-sided bars* narrowed the life expectancy gap, and *right-sided bars* widened the gap. † Data in *parentheses* refer to the years contributed to the life expectancy gap in 2002–2006 (total men = 2.3 years, total women = 1.4 years)

Table 2 Life expectancy at birth (95% confidence interval) according to sex, language spoken at home, and area of residence, Québec, 2002–2006

	Francophone	Anglophone	Absolute difference[a]
Men			
Montréal	76.6 (76.6–76.6)	78.7 (78.6–78.7)	2.1
Other metropolitan centres	77.1 (77.1–77.1)	82.2 (82.0–82.5)	5.1
Small cities/rural areas	76.1 (76.0–76.1)	76.9 (76.7–77.1)	0.8
Women			
Montréal	81.5 (81.5–81.5)	83.1 (83.1–83.2)	1.6
Other metropolitan centres	82.7 (82.6–82.7)	85.9 (85.7–86.0)	3.2
Small cities/rural areas	81.6 (81.6–81.6)	82.3 (82.2–82.4)	0.7

[a] Absolute difference in life expectancy at birth between Francophones and Anglophones

Table 4 shows that the elderly (≥65 years) contributed most to the Francophone-Anglophone life expectancy gap in Montréal and other metropolitan centres, reflecting higher mortality for Francophones (higher mortality among those aged 15–64 years also contributed). In small cities/rural areas, a reverse pattern of higher mortality among young Anglophones (<40 years) offset the gap that otherwise would have been greater. Relatively lower Anglophone mortality among older adults ≥40 years resulted in a life expectancy differential favouring Anglophones overall.

Discussion

This study examined linguistic inequalities in mortality in the only North American region where Anglophones are the minority. Unlike many settings where minorities tend to have poorer health [1–3], Anglophone minority men and women had higher life expectancy than Francophones in Québec. However, greater reductions in mortality from ischemic heart/cerebrovascular disease, lung cancer (men only) and infant mortality among Francophones narrowed the Francophone-Anglophone life expectancy gap over time. Greater increases in lung cancer mortality among Francophone women countered gains from other causes. The life expectancy gap also differed across areas of Québec, with the largest gaps observed in metropolitan areas other than Montréal, and the narrowest gaps in small cities/rural areas. In general, the same ages and causes of death were responsible for the gap in all three areas. Small cities/rural areas were an exception due to higher mortality among young Anglophones, which resulted in a narrower life expectancy gap than would otherwise have been observed.

Finland is another country where health-related linguistic inequalities have been observed. The Swedish-speaking minority in Finland tends to be in better health than the Finnish-speaking majority [10, 40, 41], and factors such as social status and social capital have been considered potential explanatory factors, though they do not completely account for differences [11, 42–47]. Anglophones in Québec have historically had higher social status [14, 16], thus their higher life expectancy is not unexpected. What is interesting however, is the decrease in the Francophone-Anglophone gap from 1989–1993 to 2002–2006. The factors driving this decrease are unclear as few studies have compared determinants of health between these two groups over time. A gradual shift in political, social and economic power from Anglophones to Francophones may be implicated [16], though any effect must work through more proximal health determinants. Some data suggest that the socioeconomic status of Anglophones outside Montréal is currently lower than Francophones, but patterns are unclear because indicators of socioeconomic status conflict for this subpopulation (Anglophone education levels are high, but employment levels are low relative to Francophones) [16, 26]. Whether changes in other risk factors have occurred, especially those related to cardiovascular disease and infant mortality, are unknown. The gain in Anglophone life expectancy from 1989–1993 to 2002–2006 may also have been slowed by upwardly mobile Anglophones who may gradually have left Québec for economic opportunities in other Canadian provinces, given that Anglophone migrants tend to be of working age and generally healthier [16]. The contribution of socioeconomic status to the decrease in the Francophone-Anglophone life expectancy gap should, however, be tempered by the fact that socioeconomic inequalities in life expectancy actually increased in Québec over time [36]. Additional research is necessary to understand the pathways through which language influences health, since socioeconomic status does not completely account for the associations.

No Finnish study has decomposed the gap in life expectancy between linguistic groups according to cause and age. Evidence indicates, however, that language-based differences are greater for mortality from alcohol use, suicide, and other injuries in Finland [10]. In the US, Canada's immediate neighbor, life expectancy gaps have been decomposed for Blacks and Whites [3]. Causes contributing to the Black-White gap in the US are somewhat different than those contributing to the Francophone-Anglophone gap in Québec. Cardiovascular disease contributed substantially in the US [3], but lung cancer and

Table 3 Causes of death contributing to the difference in life expectancy at birth between Francophones and Anglophones according to sex and area of residence, 2002–2006

	Men			Women		
	Montréal	Other metropolitan centres	Small cities/rural areas	Montréal	Other metropolitan centres	Small cities/rural areas
Absolute difference, years[a]	2.1	5.1	0.8	1.6	3.2	0.7
Decomposition of absolute difference by cause, years (%)[b]						
Circulatory system						
Ischemic heart disease	0.30 (14.4%)	0.51 (9.9%)	−0.02 (−2.5%)	0.28 (17.2%)	0.15 (4.7%)	0.04 (5.5%)
Cerebrovascular disease	0.03 (1.4%)	0.26 (5.1%)	0.04 (4.9%)	0.05 (3.1%)	0.21 (6.6%)	0.12 (16.4%)
Arterial disease	0.04 (1.9%)	0.14 (2.7%)	0.01 (1.2%)	0 (0%)	0.10 (3.1%)	−0.03 (−4.1%)
Cancer						
Lung	0.54 (25.8%)	0.85 (16.5%)	0.61 (75.3%)	0.35 (21.5%)	0.35 (10.9%)	0.20 (27.4%)
Colorectal	0.08 (3.8%)	0.21 (4.1%)	0.07 (8.6%)	0.05 (3.1%)	0.14 (4.4%)	0.03 (4.1%)
Prostate (men)/breast (women)	0 (0%)	0.18 (3.5%)	−0.02 (−2.5%)	0.06 (3.7%)	0.25 (7.8%)	0.16 (21.9%)
Pancreas	0 (0%)	0.05 (1.0%)	0.04 (4.9%)	0.01 (0.6%)	0.11 (3.4%)	0.04 (5.5%)
Stomach	−0.03 (−1.4%)	0.01 (0.2%)	0.05 (6.2%)	−0.01 (−0.6%)	0.07 (2.2%)	0.03 (4.1%)
Chronic lower respiratory	0.19 (9.1%)	0.24 (4.7%)	0.24 (29.6%)	0.14 (8.6%)	0.12 (3.8%)	0.04 (5.5%)
Infectious diseases						
Pneumonia/influenza	−0.03 (−1.4%)	0.09 (1.8%)	0.02 (2.5%)	−0.03 (−1.8%)	0.10 (3.1%)	0.01 (1.4%)
Human immunodeficiency virus	0.05 (2.4%)	0.06 (1.2%)	−0.02 (−2.5%)	0.02 (1.2%)	0.01 (0.3%)	0.01 (1.4%)
Tuberculosis	0 (0%)	−0.02 (−0.4%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)
Other reportable infections	0 (0%)	0.01 (0.2%)	−0.01 (−1.2%)	0.01 (0.6%)	0 (0%)	0.01 (1.4%)
Trauma						
Transport injuries	0.16 (7.7%)	0.12 (2.3%)	0.19 (23.5%)	0.08 (4.9%)	0.06 (1.9%)	−0.03 (−4.1%)
Falls	−0.01 (−0.5%)	0.05 (1.0%)	0.03 (3.7%)	0 (0%)	0.05 (1.6%)	0.02 (2.7%)
Other unintentional injuries	0.09 (4.3%)	0.15 (2.9%)	−0.12 (−14.8%)	0.03 (1.8%)	−0.10 (−3.1%)	−0.01 (−1.4%)
Suicide	0.31 (14.8%)	0.59 (11.5%)	0.07 (8.6%)	0.09 (5.5%)	0.17 (5.3%)	0.06 (8.2%)
Homicide	−0.02 (−1.0%)	−0.01 (−0.2%)	−0.06 (−7.4%)	0 (0%)	0 (0%)	−0.04 (−5.5%)
Diabetes	0 (0%)	0.01 (0.2%)	−0.02 (−2.5%)	0 (0%)	0.01 (0.3%)	−0.01 (−1.4%)
Alzheimer's	0.05 (2.4%)	0.05 (1.0%)	0.03 (3.7%)	0.17 (10.4%)	0.06 (1.9%)	0.05 (6.9%)
Infant mortality	0.04 (1.9%)	0.01 (0.2%)	−0.16 (−19.8%)	−0.02 (−1.2%)	0.03 (0.9%)	−0.22 (−30.1%)
Residual	0.30 (14.4%)	1.59 (30.9%)	−0.16 (−19.8%)	0.35 (21.5%)	1.31 (40.9%)	0.25 (34.3%)

[a] Absolute difference in life expectancy at birth between Francophones and Anglophones (i.e., life expectancy gap)

[b] For each area, the sum of the years contributed by all causes in the column equals the absolute difference in life expectancy (first row of data). The percentage in parentheses provides the relative contribution of each cause to the absolute difference in life expectancy, and is obtained by dividing the cause-specific contribution in years by the absolute difference and multiplying by 100. To interpret results, both the absolute and proportionate contribution of a cause to the life expectancy gap should be considered, as well as the overall gap in each area. A cause may, for example, contribute a large number of years, but have a small proportionate contribution if the overall absolute difference in the area is large (or vice versa). The gap in this area would be of concern, and actions to reduce it would require addressing several causes of death

chronic lower respiratory disease were more important drivers of the Francophone-Anglophone gap, especially in women where lung cancer mortality actually prevented the gap from narrowing further. This pattern may be related to the historic role of the tobacco industry promoting smoking to Francophone women during the mid-twentieth century as a symbol of emancipation (particularly in Montréal where a major tobacco company was based) [48].

Table 4 Age groups contributing to the difference in life expectancy at birth between Francophones and Anglophones, according to sex and area of residence, 2002–2006

	Men			Women		
	Montréal	Other metropolitan centres	Small cities/rural areas	Montréal	Other metropolitan centres	Small cities/rural areas
Absolute difference, years[a]	2.1	5.1	0.8	1.6	3.2	0.7
Decomposition of absolute difference by age group, years (%)[b]						
<1	0.04 (1.9%)	0.02 (0.4%)	−0.15 (−17.9%)	−0.01 (−0.6%)	−0.05 (−1.6%)	−0.21 (−29.6%)
1–14	0.03 (1.4%)	0.11 (2.1%)	−0.31 (−36.9%)	0 (0%)	−0.01 (−0.3%)	0.04 (5.6%)
15–44	0.45 (21.6%)	0.87 (16.9%)	−0.32 (−38.1%)	0.25 (15.2%)	0.35 (10.9%)	−0.22 (−31.0%)
45–64	0.71 (34.1%)	1.15 (22.4%)	0.24 (28.6%)	0.49 (29.9%)	0.80 (25.0%)	0.17 (23.9%)
≥65	0.84 (40.4%)	2.99 (58.2%)	1.39 (165.5%)	0.92 (56.1%)	2.11 (65.9%)	0.92 (129.6%)

[a] Absolute difference in life expectancy at birth between Francophones and Anglophones (i.e., life expectancy gap)

[b] The percentage in parentheses provides the relative contribution of each cause to the absolute difference in life expectancy for each area

Targeting of women by the tobacco industry has been observed in other settings also [49, 50]. Past tobacco marketing to Francophone women may have influenced smoking habits, explaining why lung cancer mortality is now the principal cause of death driving Francophone-Anglophone inequality in life expectancy among women. Lung cancer may, however, become a less important contributor over time. Data suggest that patterns of tobacco use were relatively similar between Francophones and Anglophones in 1998 [15].

Tobacco-related deaths in both sexes, including lung cancer, were also the outstanding cause of the current Francophone-Anglophone life expectancy gap for all areas of Québec, reflecting greater Francophone smoking rates in the past century [51]. Alcohol-related causes among men (including transport injuries for those aged 15–39) were the second most important contributors due to higher mortality among Francophones, especially in Montréal and small cities/rural areas. Patterns of alcohol use between Francophones and Anglophones tend to differ with more frequent consumption and intoxication in Francophones [7, 15], which is reminiscent of Finland where Finnish-speakers also tend to consume more alcohol and have higher alcohol-related mortality relative to Swedish-speakers [10, 52].

Suicide was another important contributor to the gap. Suicide rates in Québec are among the highest in the Western world [53]. Results suggested that suicide was more common among Francophones, particularly men aged 15–49 years who accounted for 0.36 years (15.7%) of the gap in 2002–2006. Why suicide may be more frequent in young Francophones is unclear, but may have historical roots. Suicide may have been viewed as a solution to oppressive life conditions, remaining a cultural norm over time, even with improvement of such conditions. Interestingly, survey data from 1998 suggest that rates of suicidal ideation and attempts were similar for Francophones and Anglophones in Québec [15].

Infant mortality, while important in the US [3], no longer drove the Francophone-Anglophone gap in Québec by 2002–2006, except in small cities/rural areas where infant mortality was greater for Anglophones. In fact, generally higher mortality of young Anglophones coupled with lower mortality at advanced ages (relative to Francophones) resulted in an overall narrow life expectancy gap in these areas. Linguistic barriers to employment or education among Anglophones in small cities/rural areas could be involved [26]. Linguistic barriers to health care services [7, 54, 55] are unlikely to explain our findings since mortality was lower in older Anglophones (relative to Francophones) despite probably greater consumption of health care at advanced ages.

Breast cancer was an important contributor in other metropolitan centres and small cities/rural areas (but not Montréal), due to higher mortality in Francophones. Québec has universal breast cancer screening [56]. Assuming that breast cancer screening improves survival, our findings suggest that screening (or survival) may be lower in Francophones outside Montréal. These findings, as well as 1998 survey data on use of mammography [15], suggest that access to English health services including screening is less problematic for Anglophones. Higher socioeconomic status, a potential risk factor for breast cancer, may also be implicated. Alzheimer's disease was an important contributor among women in Montréal. Over time, mortality from Alzheimer's disease slightly prevented the life expectancy gap from narrowing further, due to rate increases slightly greater for Francophones than Anglophones. The basis for these results is unknown, but may be related to differential patterns in population aging between language groups.

Limitations of this study include the issue that inference cannot be made for individuals, as analyses were ecologic. We could not account for socioeconomic status, ethnicity, or immigration, which may partly account for the observed gradients. Hence, we cannot determine the extent to which linguistic status might be a proxy for other unmeasured factors related to life expectancy. Such factors may, however, be mediators. Coding of principal cause of death changed from the ninth to tenth revision of the ICD in 2000, though this change likely affected language groups non-differentially. Secondary or competing causes of death were not evaluated. Results should be interpreted with caution for small cities/rural areas, given fewer Anglophones in these areas. Accuracy of language coding on death certificates has not been established, through misclassification is likely non-differential. Denominators for rates were obtained from the census for which there is uncertainty related to comparability with death counts used in the numerator. The death file records the language spoken at home, while the census records the language most often spoken at home. This slight difference in the definition of language was, however, not differential over time (i.e., language definitions were the same in both periods). We did not have linguistic population data for other census years and could not assess life expectancy gaps for central periods. Finally, Arriaga's decomposition method assumes that the contribution of each cause of death to each age group's overall contribution to life expectancy change is proportional to the change in the fraction of deaths due to that cause. New methods comparing the sensitivity of this assumption to alternative methods are generally consistent with our approach, but also suggest that our findings may be conservative because Arriaga's method may underestimate the contributions for common causes of death heavily concentrated at older ages [57, 58].

In summary, life expectancy in Québec favoured Anglophones over Francophones, but the gap decreased over time due to sharper reductions in Francophone mortality from several causes. Tobacco-related causes were the main contributors to the current life expectancy gap, preventing the gap from narrowing further in women. Tobacco control and prevention programs targeting Francophones, especially women, are needed to equalize life expectancy between linguistic groups. Further research is needed to identify the underlying factors driving the relationship between language and health.

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Conflict of interest The authors declare that they have no competing interests.

Appendix 1. Statistical description of Arriaga's method for decomposing a life expectancy gap

Changes in life expectancy over time (or differences between populations at the same time) are a function of changes (or differences) in age-specific mortality. For each age group, Arriaga's method estimates how many years of life expectancy at birth are added (or removed) due to change (or difference) in age-specific mortality rates. For example, the effect ($_n\Delta_x$, in years) of mortality change from 1990 to 2001 between ages x and $x + n$ on the change in life expectancy at birth is calculated as

$$
\begin{aligned}
{}_n\Delta_x = &\left[\frac{l_x^{1990}}{l_0^{1990}} \times \left(\frac{{}_nL_x^{2001}}{l_x^{2001}} - \frac{{}_nL_x^{1990}}{l_x^{1990}}\right)\right] \\
&+ \left[\frac{T_{x+n}^{2001}}{l_{x+n}^{2001}} \times \frac{\frac{l_x^{1990} l_{x+n}^{2001}}{l_x^{2001}} - l_{x+n}^{1990}}{l_0^{1990}}\right]
\end{aligned} \tag{1}
$$

where l_x is the number surviving to age x out of a synthetic cohort (l_0 is the cohort size, typically 100,000 in a period life table), ${}_nL_x$ is the number of person-years lived between ages x and $x + n$, and T_{x+n} is the total number of person-years lived above age x. The first term on the right of Eq. 1 is the direct effect of mortality change between ages x and $x + n$, or the change in the number of years lived between ages x and $x + n$. The direct effect is the product of the fraction of the cohort surviving to age x in 1990 (l_x/l_0) multiplied by the change in the average number of person years lived from ages x to $x + n$ (${}_nL_x/l_x$) between 1990 and 2001. There is also an indirect effect of mortality change *within* an age interval because the direct effect produces additional survivors at the end of the interval, and an additional interaction effect due to the additional survivors who are exposed to new mortality conditions in the later period [17]. The second term on the right of Eq. 1 captures the indirect and interaction effects, and is the product of the life expectancy remaining at age $x + n$ after the mortality change (T_{x+n}/l_{x+n} in 2001) and the fraction of additional survivors in the birth cohort [18]. For the last age group (90 + years), there is only a direct effect of mortality change. The decomposition between language groups in a given year is obtained by replacing year in Eq. 1 (1990, 2001) with language (Francophone, Anglophone).

In addition, the overall contribution of each age group may be partitioned by cause of death under the assumption that the contribution of each cause to the life expectancy change for an age group is proportional to the contribution of each cause to the change in the overall age-specific mortality rate [19]. The literature suggests this is a

reasonable assumption, but estimates of the contributions for common causes of death heavily concentrated at older ages may be conservative [57, 58]. The contribution to mortality change of cause i within ages x and $x + n$ from 1990 to 2001, ${}_n\Delta_x^i$, is estimated as

$${}_n\Delta_x^i = {}_n\Delta_x \times \frac{\left({}_np_x^{i,2001} \times {}_nr_x^{2001}\right) - \left({}_np_x^{i,1990} \times {}_nr_x^{1990}\right)}{{}_nr_x^{2001} - {}_nr_x^{1990}}, \quad (2)$$

where ${}_np_x^i$ is the proportion of deaths between ages x and $x + n$ due to cause i, and ${}_nr_x$ is the all-cause mortality rate between ages x and $x + n$. Thus the contribution of a change in a specific cause of death is a function of both the absolute change in age-specific mortality (${}_nr_x$) and the change in the distribution of the cause over time relative to other causes (${}_np_x^i$). From Eq. 2, it is inferred that causes of death less frequent in 2001 than in 1990 will make positive contributions to the overall positive change in life expectancy at birth, while causes of death more frequent in 2001 will make negative contributions.

Appendix 2

See Table 5.

Table 5 International classification of disease (ICD) codes for causes of death

	ICD-9	ICD-10
Circulatory system		
Ischemic heart disease	410–414, 429.2	I20–I25
Cerebrovascular disease	430–434, 436–438	I60–I69
Arterial disease	440–448	I70–I78
Cancer		
Lung	162	C33–C34
Colorectal	153–154	C18–C21
Breast	174	C50
Prostate	185	C61
Pancreas	157	C25
Stomach	151	C16
Chronic lower respiratory	490–494, 496	J40–J47
Infectious diseases		
Pneumonia/influenza	480–487	J10–J18
Human immunodeficiency virus	042–044	B20–B24
Tuberculosis	010–018	A15–A19
Other reportable infections	008.0, 033, 036, 038.0, 038.2, 038.4, 041.5, 070.0–070.2, 070.5, 091–092, 098, 099.8, 320.0	A04.3, A37, A39, A40.0, A40.3, A41.3, A49.2, A51, A54, A56, B15, B16, B18.2, G00.0
Injury		
Transport injuries	E800–E848, E929.0, E929.1	V01–V99, Y85
Falls	E880–E888	W00–W19
Other unintentional injuries	E849–E869, E889–E928, E929.2–E929.9	W20–W99, X00–X59, Y86
Suicide	E950–E959	X60–X84, Y87.0
Homicide	E960–E969	X85–Y09, Y87.1
Diabetes	250	E10–E14
Alzheimer's	331.0	G300, G301, G308, G309
Infant/perinatal	740–766,770–779, 798.0	Q00–Q99, P00–P19, P22–P96, R95
Tobacco-related mortality	140–150, 161, 162, 410–414, 430–438, 490–496	C00–C15, C32–C34, I20–I25, I60–I69, J40–J47
Alcohol-related mortality	150,161, 303, 571, E800–E999	C15, C32, F10, K70, K73, K74, K76, V00–V99, W00–W99, X00–X99, Y00–Y99

Appendix 3

See Table 6.

Table 6 Cause-specific age-adjusted mortality rates according to sex and language spoken at home, Québec, 1989–1993 and 2002–2006

	Men				Women			
	1989–1993		2002–2006		1989–1993		2002–2006	
	French	English	French	English	French	English	French	English
All causes	1279.1	911.9	957.8	800.1	698.5	552.2	594.3	517.6
Circulatory system								
Ischemic heart disease	308.0	230.2	161.1	147.3	151.8	108.9	78.7	68.9
Cerebrovascular disease	72.9	49.4	41.0	36.2	56.3	41.5	32.6	27.4
Arterial disease	33.9	21.7	16.4	12.6	16.0	11.2	7.3	6.8
Cancer								
Lung	146.2	79.9	113.6	67.8	39.9	36.2	57.3	43.3
Colorectal	42.2	31.0	38.2	31.8	28.6	20.2	23.6	20.7
Prostate (men)/Breast (women)	40.4	33.8	27.0	26.4	42.4	37.9	32.4	29.4
Pancreas	16.4	13.3	14.3	13.5	10.8	9.1	11.3	10.3
Stomach	17.6	11.9	11.0	10.8	7.7	4.9	4.9	4.7
Chronic lower respiratory	87.4	44.9	59.3	33.0	26.5	19.3	28.4	22.3
Infectious diseases								
Pneumonia/influenza	28.2	33.8	15.4	17.1	16.1	18.5	9.9	10.7
Human immunodeficiency virus	9.6	9.5	2.9	2.5	0.9	0.5	0.5	0.3
Tuberculosis	1.0	0.7	0.3	0.3	0.4	0.3	0.2	0.2
Other reportable infections	0.6	0.4	0.9	1.2	0.4	0.6	0.7	0.5
Injury								
Transport injuries	24.6	11.5	17.0	7.8	9.7	5.1	6.3	2.8
Falls	11.0	8.3	5.9	6.0	6.9	5.9	2.4	1.7
Other unintentional injuries	14.5	7.8	17.2	11.8	4.4	3.8	9.9	9.3
Suicide	30.2	12.1	29.2	12.4	7.5	3.1	8.4	4.2
Homicide	2.9	3.0	1.5	2.5	1.5	0.8	0.8	1.0
Diabetes	1.0	0.7	1.0	1.0	0.6	0.5	0.4	0.5
Alzheimer's	10.4	10.1	19.0	13.9	10.8	8.8	24.3	17.1
Infant mortality	6.9	4.4	4.2	3.7	5.3	4.0	3.8	4.1
Residual	373.4	293.4	361.5	340.6	254.1	211.1	250.4	231.5
Tobacco-related mortality	623.3	408.2	380.9	289.1	274.9	206.9	198.9	164.1
Alcohol-related mortality	104.8	58.0	87.6	55.6	38.0	25.3	34.8	23.9

Directly standardized rates per 100,000 population (2006 population as referent)

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