HSTP Research Report

Data Visualization of Complex Health Information: Communicating Multiple-Cause Mortality and the Social Determinants of Health

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What is known?

- The social determinants of health (SDOH), specifically socioeconomic status are key mortality indicators.
- Basic demographic patterns that shape our understanding of mortality are presented in tables or charts.

What does this report add?

- The potential to interpret datasets through interactive visualizations to analyze the associations between SDOH and mortality.
- The creation of four interactive and accessible Lexis shiny applications for use in research, education, public health, and the general public.

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Executive Summary

Background: Epidemiology and public health are grounded by the use of core demographic statistics, such as mortality rates and life expectancy. Indicators such as mortality rates are usually presented as tables or basic charts; however, there is significant potential in data visualization techniques to improve understanding and dissemination of these statistics. This project aims to use interactive visualizations to interpret Canadian mortality indicators by age, sex, socioeconomic status, and cause of death.

Methods: Visualizations were developed using compositional Lexis surface diagrams, age-wise plots, and plots of small-multiples. Recent and historical data on deaths by age, sex, and selected cause and population counts were sourced from the Human Mortality Database and Statistics Canada Vital Statistics files. Data cleaning and analysis were conducted using R and RStudio, with open-source code shared via GitHub. For each visualization type, interactive applications were developed using Shiny and made available publicly online via open access.

Results: Four interactive Shiny applications were produced: (1) a Lexis Surface Plot from 1921-2022; (2) Small Multiples Plot from 1950-2019; (3) Multiple Lexis Surface Plots from 2002-2021; and (4) Age-Wise Plots 1950-2019 and 2002-2021. Each plot includes written evidence-based descriptions on the association between mortality and other factors. These tools will be useful to provide insight into longitudinal mortality patterns for students, researchers, public health agencies, and the general public.

Conclusion: Interactive visualizations provide enhanced insight into mortality analysis. Visualizations can be modified to include features that improve accessibility for diverse audiences. Future research can expand the use of Lexis diagrams to create applications at disaggregated levels to support health research and policy.

Keywords: Mortality, Social Determinants, Demography, Population Health, Data Visualization, Accessibility

Background

Mortality and the Social Determinants of Health

Mortality rates and proportions of death are crucial demographic indicators that are commonly used within epidemiological and public health studies to better understand diseases, patterns, and health status across different populations[1]. Mortality statistics are often presented in tabular formats or charts, which is not always accessible to the general public. There is a significant potential to incorporate data visualizations that allow for access and a better understanding of fundamental mortality patterns[2].

Commented [AV1]: problem

The Social Determinants of Health (SDOH) are the conditions in which people are born, grow, live, work, and age[3]. Socioeconomic status (SES), age, sex, environmental conditions, education level, healthcare access, and social context are all common SDOH indicators that can shape mortality outcomes[4]. Evidence from national datasets and research demonstrates that SDOH-related factors are associated with a higher risk of negative health outcomes and mortality[4]. Mortality does not always stem from a single cause of death but occurs through a combination of multiple health conditions and SDOH factors[1]. Although mortality statistics tend to only record the underlying cause of death, there is a need to understand and recognize that SDOH factors can shape contributing causes of death[2, 4].

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This project aims to use complex data visualization techniques and interactive applications to visualize SDOH indicators, specifically age, sex, and socioeconomic status, alongside mortality patterns. Additionally, colourblind schemes and accessible design features were taken into consideration in the creation of these visualizations to help stakeholders and audiences engage with the data effectively. Increasing health literacy, supporting evidence-based public health preparedness, and informing health policy can be enhanced through the use of interactive Lexis diagram applications.

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An Introduction to Lexis Diagrams

This project was based on the data visualizations and R code that were provided and created by Jonas Schöley and Franz Willekens, where they analyzed England and France data from the human mortality database in 2017[5]. Lexis diagrams are a demographic tool that can visualize compositional data, which can be represented by death proportions[5]. These diagrams allow users to visualize additional metrics including age, death counts by cause of death, and sex[5]. Despite the potential of Lexis diagrams, there is a lack of interactivity, accessibility, and integration of SDOH and SES indicators to strengthen its use in research and public health practice.

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The first visualization featured within this project is the Lexis surface, which focuses on analyzing different age groups and proportion of death by sex ratio[5]. Male-female mortality ratio varies by colour and death proportion, where higher male mortality contains darker blue hue, and higher female mortality contains a red hue[5]. One of the Lexis surface visualizations feature Canadian data from the Human Mortality Database (HMD), and the other diagram features Vital Statistics Canada data to filter for socioeconomic status (QAIPPE). The first Lexis graph ranges from the years 1921 to 2022 to provide a historical overview of male-female proportion of deaths in Canada whereas the second Lexis Surface has a smaller timeline between 2002 to 2021 to allow for socioeconomic indicators.

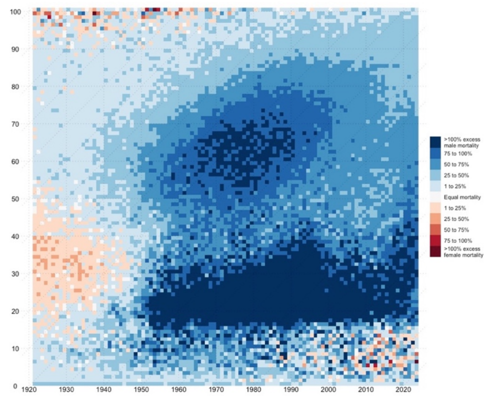

Figure 1. *Lexis Surface diagram using Canadian Human Mortality Database (HMD) data featuring sex ratios.*

The second visualization featured in this project is known as Small Multiples, which consists of a collection of heatmaps that demonstrate different subsets of a dataset[5]. Small Multiples can be used to visualize different age groups, gender, and causes of death, which are useful in determining social determinants of health outcomes[2,5]. In this project, users will be able to select cause of death among the top sixteen highest causes of death featured in the Human Mortality Database short-list data as well as toggle between male, female, and both.

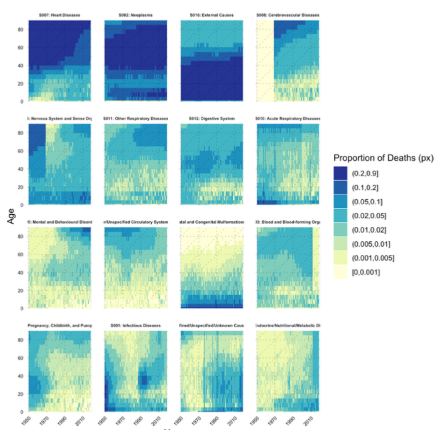

Figure 2. *Small multiples plot using HMD data. This static graph was created in the early stages of this project and was later converted to an application where the titles were expanded and one graph at a time is shown to ease visibility.*

The third visualization featured within this project is the Age-wise area plot that resembles a stacked-bar chart but has a stacked area instead[5]. The y-axis features a range between 0% to 100%, which helps users identify which causes of death had a larger percentage of death for a specific age group and year. A legend also serves as a guide for users to distinguish between the various colour-coded causes of death:

infectious diseases, neoplasms, heart diseases, respiratory diseases, and external causes of death[5]. The original static age-wise plot does not feature socioeconomic data; therefore, this project features a radio-button filter for users to examine different income levels on the shiny app.

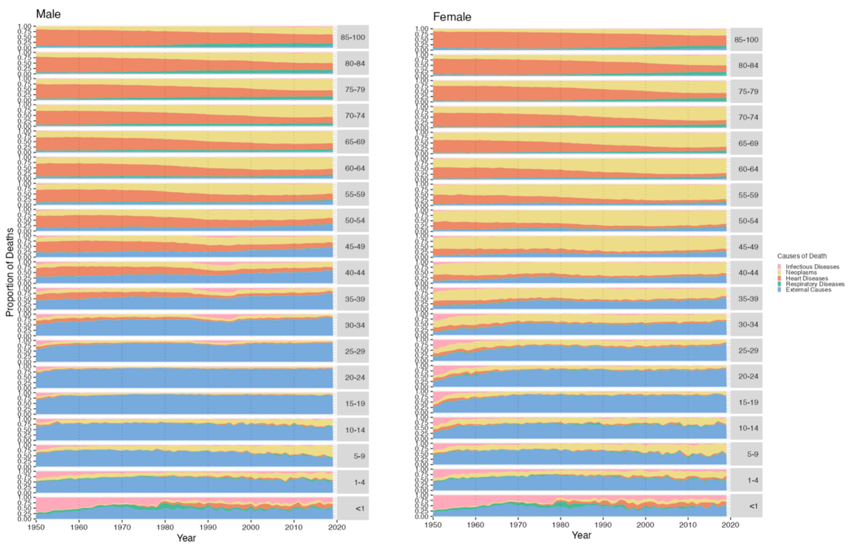

Figure 3. *Age-wise plots using HMD data. This plot features male and female proportions of death for infectious diseases, neoplasms, heart diseases, respiratory diseases, and external causes of death from 1950 to 2019.*

Lexis diagrams were used in this project as they incorporate heatmap-style visuals, legends, age- and sex-specific demographics that are easier for audiences to interpret[5]. The original static Lexis diagrams have been enhanced and modified into interactive applications and incorporate socioeconomic status metrics.

Methods

Data

This project used data from the Human Mortality Database which is publicly available and Statistics Canada which was privately sourced by obtaining security clearance to Carleton University's Research Data Center (CURDC). An account was created on the Human Mortality Database to obtain Deaths by Cause short-list, population data (*CANpop*), and deaths from 1950 to 2019 (*Deaths_1x1*). Vital Statistics, Deaths data, which was updated in 2023, was vetted from the CURDC to remove any participant identifiers for data manipulation and analysis to obtain socioeconomic metrics.

Data Manipulation in R

R is a coding language that is widely used in research for statistical computing, data analysis, creating graphics and visualizations, and to design websites and applications[6]. The main reason R was used for this project is that it is open and accessible to the general public for use, it allows for the ability of creating complex data visualizations using popular graphing and data wrangling packages, and it is compatible with Shiny to publish applications to the web[6]. R was also used in Schöley's analysis, allowing for easier replication and editing of their original Lexis code provided by GitHub[5].

The *dplyr* and *tidyr* are popular R packages that aid in the manipulation of raw data. These packages were used in the making of this project to transform raw HMD and Vital Statistics data into cleaner tabular datasets to ease the creation of the graphs and apps. The widely known ggplot2 package was used to convert the tabular datasets into Lexis diagrams and allowed for accessible features such as filters and colour palettes to be added onto the graphs. The *plotly* package was used for interactivity and allowing for users to hover their mouse over the diagrams for more accurate information. The Shiny package was used to create four different apps containing their respective data visualizations, filters such as cause of death, sex, and *QAIPPE*, and a panel to provide users with SDOH information. These packages were chosen due to their similar use in the original Lexis codes obtained in GitHub, although this project added *plotly* and Shiny to allow for interactivity which was not previously done in past research.

Methods

The proportion of death (*px*) was the key metric used to analyze mortality patterns in this project. This measurement was chosen as this project seeks to understand the proportion of those who died from a specific cause within a year, age group, and sex category. Both HMD data and Vital Statistics datasets had a different, but similar process due to the differences in their raw data. For the HMD dataset, each year, age group, and sex, the *px* was calculated by dividing the number of deaths attributed to a specific cause of death (*deaths_numeric*) by the total number of deaths from all causes recorded within the same year, age, and sex categories (*total_deaths*).

This calculation can be shown as:

$$px = \frac{deaths\_numeric}{total\_deaths}$$

Where *deaths_numeric* is the number of deaths from a specific cause of death and *total_deaths* is the number of deaths from all causes across the same year, age group, and sex.

In the Vital Statistics dataset, HMD population data was joined using inner-join and left-join to effectively calculate mortality rates. *px* was calculated by dividing the number of deaths from a specific cause of death (*rndCnt_adj*) by the total population within the same year, age group, sex (*pop_value*). This allows for a cause-specific death rate calculation within each socioeconomic group, by dividing the total population (*grp_tots*) evenly across five *QAIPPE* categories (*QAIPPE* = 1 – *QAIPPE* = 5), where *QAIPPE* = 0 was not divided as it represents all incomes.

This calculation can be shown as:

$$Px = \frac{rndCnt\_adj}{pop\_value}$$

Where *rndCnt_adj* is the number of deaths of a specific cause of death across year, age group, and sex categories and *pop_value* is the total number of people recorded in the population for the same categories, divided across socioeconomic income groups 1 to 5 or, for group 0 which accounts for the full population.

All other calculations for analyzing the data were obtained from and based on Schöley's original R code files publicly available on their GitHub under jschoeley/viscomplexis and under this project's GitHub Alie-23/Mortality_Lexis_Proj[5].

GitHub Integration

To ease transparency and replicability practices for research purposes, all of the code used in this project along with the shiny application script is located under Alie-23/Mortality_Lexis_Proj which is publicly available on GitHub. Project progress code is located under the "Old code (project progress)" folder, whereas the full and finalized code for the four applications are available in the "Full Finalized Code Files" folder. The use of GitHub for this project also allowed for protection of these files in case of sudden loss of data and for seamless distribution between the project members. Folders were created in GitHub which contain project progress code for transparency purposes which organize code files by dataset, *ggplot2* code, and Shiny app. A separate folder containing the full script for each app is also available on GitHub. This technique was used for public health agencies and researchers to reorganize the code and publish.

Process for Publishing Applications

After the data and Shiny apps were created, four apps were published using the *rsconnect* package in R to deploy them as shinyapp.io format on the internet[7]. Due to higher volume of data being processed, the paid version of shinyapp.io was used to publish these applications, although it is still possible to publish under the free version if the files are less than 25MB[7].

Results: Application & Visualization

Lexis Surface Plot: Mortality in Canada Based on Sex and Age from 1921-2022

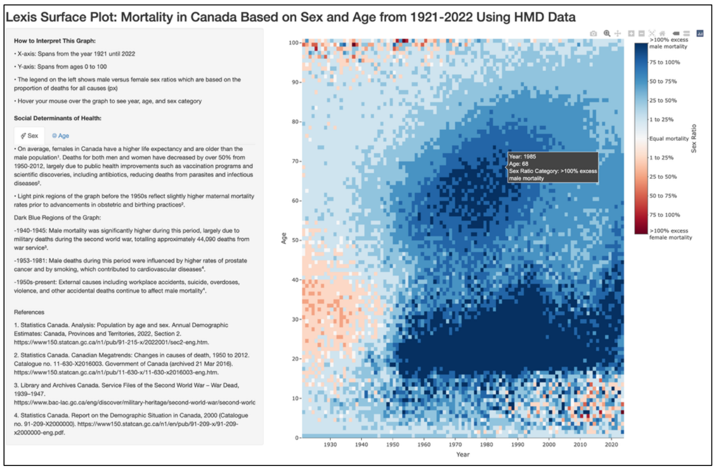

Figure 4. *The following is an image of the completed HMD Lexis Surface Shiny application. Hover function is enabled to allow users to get insights on the year, age, and sex mortality ratio, obtained from px.*

Figure 4 demonstrates the Lexis surface plot using HMD data from 1921 to 2022. The *deaths1x1* and *Canpop* datasets were soured publicly and directly from HMD using the *HMDHFDplus* package in R. Clear information is available on the left hand-side of the application for users to interpret the graph and understand the SDOH association in the diagram. The legend on the right-hand side displays the colour white for equal mortality ratio between males and females, blue for higher mortality in males, and red for higher mortality in females. Results obtained from this graph demonstrate that there is a higher male mortality ratio compared to females. Males are at higher risk of deaths from external causes within the ages of 15 to 30 due to suicides, overdoses, workplace accidents, violence, and other accidental deaths[8,9]. Over the age of 45, men are at higher risk of mortality from prostate cancer and cardiovascular diseases, which may stem from smoking habits[9]. Fortunately, this trend has begun to decrease since the early 2000s with advances to cancer screening and diagnosis[10]. Female deaths prior to 1950 between the ages of 19 to 50 may have been caused by infections and childbirth[11]. Mortality due to childbirth complications has since decreased drastically due to advances in obstetric and birthing care practices[11]. This application may serve as a tool for educating the general public and for researchers and public health agencies to understand overall mortality trends in Canada from a historical perspective, since long-term data can significantly aid in improving and monitoring health inequities and diseases that affect our society in present day[12]. Future Lexis sex ratio diagrams should focus on implementing automatically updated datasets and linking socioeconomic data for advanced filtering.

Small Multiples Plot: Analysis of Sex, Age, and Cause of Death from 1950-2019

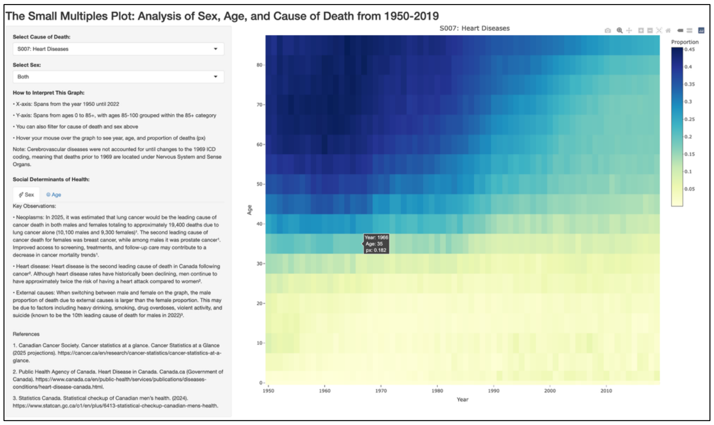

Figure 5. *The following is an image of the completed HMD Small Multiples Shiny application. Hover function is enabled to allow users to get insights on the year, age, and px.*

Figure 5 demonstrates a heatmap style Small Multiples diagram that can filter between causes of death and sex. The legend to the right features a proportion of death scale that adjusts based on the cause of death that has been filtered, where darker blue regions contain a higher proportion of death whereas yellow regions contain the lowest. Similarly to the Lexis Surface plot, there is an SDOH information tab on the left-hand side that associates the results on the graph with sex and age indicators based on evidence-based literature. The results demonstrate key observations, specifically surrounding heart disease, neoplasms, and external causes of death, which have the most noticeable differences compared to other causes of death in this application. Lung cancer is the leading cancer-related cause of death among both men and women[10, 13]. Breast cancer is the second leading cancer-related cause of death among women whereas for males it is prostate cancer[10]. Additionally, age is an important SDOH factor in this data, since there is higher risk of cancer over age 50 and females are at higher risk of mortality from cancer between the ages of 20 to 59 compared to males[10]. Due to advances in healthcare practices, there is a significant decrease of deaths from preventable causes such as infections, which has made deaths from cancer one of the leading causes of death in Canada in present day[10, 13]. Heart disease is also one of the top leading causes of death in Canada[14]. Although deaths from heart disease have decreased since the 1990s, it continues to affect males above the age of 50, whereas females 65 years[14]. External causes are more dominant in males between the ages of 15 to 30, whereas for women 15 to 20[15]. This may be due to several SDOH factors including smoking, exposure to violent activity, overdoses, and suicide, where men are three times more likely to commit suicide within this age group[15]. This application is useful for researchers and public health agencies, but it also may aid in future policy decision-making for implementing early screening and expanding mental health care for younger populations[16]. Future small multiples diagrams should focus on automatically updated data, add COVID-19 and novel diseases as a cause, and incorporate socioeconomic data for advanced filtering.

Multiple Lexis Surface Plots: Analysis of Sex, Age, Cause of Death, and Socioeconomic Status from 2002-2021

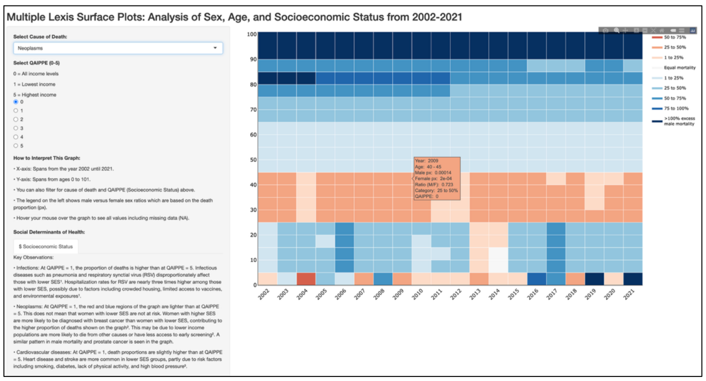

Figure 6. *The following is an image of the completed Vital Statistics Multiple Lexis Surface Plots Shiny application. Hover function is enabled to allow users to get insights on the year, age, male px, female px, mortality sex ratio and its category, and QAIPPE.*

The second Lexis diagram focuses on analyzing cause of death, sex, age, and socioeconomic status from 2002 to 2021. On the left-hand side, users are able to select income quintiles 0 to 5 (*QAIPPE*), where 0 is all income levels, 1 is the lowest, and 5 is the highest. Additional information on the SES indicator is provided to associate mortality and income levels based on evidence-based literature. One of the main limitations of this Lexis Surface is the lack of long-term historical data available, which decreases the amount of data that can be analyzed compared to the HMD Lexis Surface graph. The results from this graph demonstrate significant trends in infections, neoplasms, and cardiovascular diseases in relation to SES. When filtering for infections at *QAIPPE* = 1, the proportion of deaths is higher than at QAIPPE = 5. Infectious diseases such as pneumonia and respiratory syncytial virus (RSV) disproportionately affect those with lower SES[17]. Hospitalization rates for RSV are nearly three times higher among those with lower SES, possibly due to factors including crowded housing, limited access to vaccines, and environmental exposures[17]. When filtering for neoplasms at *QAIPPE* = 1, the red and blue regions of the graph are lighter than at *QAIPPE* = 5. This does not mean that women with lower SES are not at risk. Women with higher SES are more likely to be diagnosed with breast cancer than women with lower SES, contributing to the higher proportion of deaths shown on the graph, which similarly occurs with prostate cancer in males[18]. This may be due to lower income populations are more likely to die from other causes or have less access to early screening[18]. For cardiovascular diseases at *QAIPPE* = 1, death proportions are slightly higher than at *QAIPPE* = 5. Heart disease and stroke are more common in lower SES groups, partly due to risk factors including smoking, diabetes, lack of physical activity, and high blood pressure[19]. This application may be useful in health research and policy for better understanding the link between socioeconomic status and mortality to address health inequities[20]. Future Lexis Surface graphs with socioeconomic data should implement historical data to ease interpretation for epidemiological patterns and incorporate novel causes of death such as COVID-19.

Age-Wise Plots: Analysis of Age, Cause of Death, and Socioeconomic Status from 1950-2019 and 2002-2021

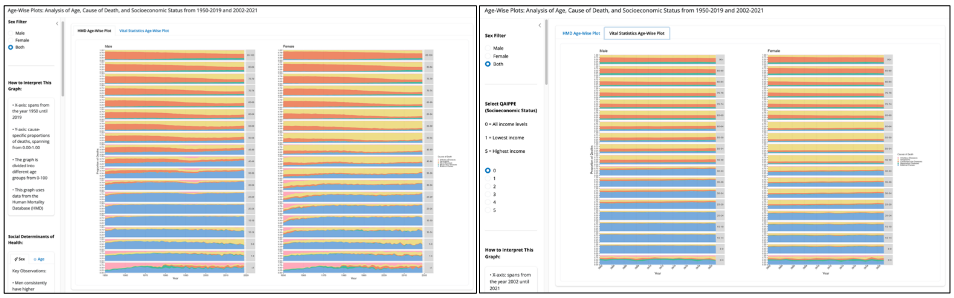

Figure 7. *The following are images of the completed HMD Small Multiples Shiny application. Filters and tabs allow users to change between datasets and get insights on the year, age, px, and QAIPPE.*

The age-wise application features both datasets from HMD and Statistics Canada, where users can switch between datasets to filter for different SDOH indicators including age, sex, and socioeconomic status. The legend to the right features the following colour-coded causes of death: infectious diseases, neoplasms, cardiovascular diseases, respiratory diseases, and external causes, in accordance with the original Lexis methodology[5]. When the user filters for "both" sexes, a side-by-side comparison between male and female mortality is visible. This was done to mitigate the technical limitation of not having hover interactivity since *plotly* was not compatible with this specific graph type. The results consistently demonstrate that men have higher mortality rates compared to women[21]. In the second tab, lower socioeconomic status is an indicator of higher mortality rates. It is important to note that men with higher SES tend to have lower mortality rates than women with lower SES, suggesting that social status and income may be more influential factors in determining health than sex[21]. Having lower SES is associated with a higher risk of avoidable deaths, including suicide and injury-related deaths, whereas higher SES is associated with a higher risk of mortality from cancer[18, 22]. When filtering for infections in the HMD tab from approximately 1950 to 1960, deaths due to infections were higher in females, but advances in birthing and obstetric care in Canada have since lowered these death rates[11]. Between the early 1980s until the early 2000s, a significant number of deaths from infections in both males and females may have been due to HIV/AIDS[23]. Deaths from HIV/AIDS have declined since 1996 after advancements in antiretroviral therapies[23]. Other observations seen in the previous diagrams are also visually present in the age-wise plots including cancer, heart disease, and external causes of death patterns. Age-wise plots may be useful in research and public health as it includes both historical and socioeconomic data for observing changes in mortality patterns, tracking diseases, and addressing health inequities for policy change[2, 12]. Additionally, this tool may be useful for educating the general public since health education is crucial in combatting low health literacy levels, an issue that risks mitigating poor health outcomes[24]. Future age-wise plots should include hover interactivity to visualize the data clearly, add novel diseases including COVID-19, and should be scaled for region-based and rural locations as these locations are often overlooked and are at risk of higher mortality[25].

Discussion

Impact on Healthcare and Research

Healthcare settings and public health agencies can greatly benefit from the use of complex data visualizations that capture mortality and SDOH patterns[2]. These tools can benefit in educating general audiences to increase health literacy, allow for resource allocation in event of outbreaks, and inform health policy[23]. In Canada, approximately only 9% of adults report a strong understanding of health data[26]. Additionally, 60% of adults over the age of 16 and 88% of elderly are not health literate, making it imperative to create accessible and educational data visualizations to aid in addressing this public health issue[27]. Accessible and clear visualizations are a form of knowledge dissemination that can aid the general public in understanding and interpreting complex or large datasets[28]. By making tools like Lexis diagrams more interpretable for diverse audiences, public health outcomes can be influenced by changes in public perception, attitudes, and decision-making[28, 29].

Lexis data visualizations can also be useful for researchers, public health professionals, and hospital decision support departments in the event of outbreaks and emergency preparedness[30]. Interactivity enhances the interpretation of large and complex datasets, which are crucial in identifying emerging mortality trends to allocate resources effectively[30]. As seen during the COVID-19 pandemic, emergency preparedness was critical in addressing increases in mortality, which underscores the importance of interactive visualizations to provide updated disease surveillance and data-driven decision support[30].

Health policy is another field that benefits from the use of interactive data visualizations. As seen in the Lexis diagrams SDOH analysis tab, young Canadian males between the ages of 15 to 30 are at risk of death from preventable mortality, including but not limited to suicide, workplace accidents, violence, and overdoses[15]. By clearly highlighting populations that are at risk, these data visualizations are able to guide policymakers to design targeted interventions, such as expanding mental health care services for young men or workplace safety regulations[16]. Interactive Lexis diagrams may also inform policy changes that support socioeconomic groups facing higher mortality rates to address health inequities, as interactive tools can represent SDOH and disparities to improve communication with policymakers and develop evidence-based policy interventions[16, 20]. Lastly, health researchers may use Lexis visualizations for reporting and monitoring mortality in regional and rural settings, as oftentimes these smaller communities are exposed to vulnerable SDOH outcomes and are at higher risk of mortality[25].

Strengths and Limitations

A strength of this project is that the Lexis code and app visualizations are compatible with Python, which is more commonly used than R. Meaning that researchers and public health professionals can adapt the code for local datasets if they use Python. Another strength is the use of *bslib* and shiny widgets packages which allowed for all apps to be consistently formatted and maintain the same accessible design. The *YlBuGn*, *RdBu* and Paul Tol colour palettes were also used for colourblind audiences to visually understand the data with ease[31]. Lastly, all complete files are uploaded to GitHub for unlimited access, meaning that researchers and other healthcare professionals can download the code and modify it according to their desired datasets.

One of the main limitations of this project is that the visualizations are estimates. Since the data used in this project comes from various sources, it is not fully precise; however, the patterns are still consistent with clinical findings that are documented in the literature. Another limitation is that socioeconomic data was only available from 2002 to 2021, which limits the amount of income-related historical data that is available. To overcome this, the apps that contain socioeconomic data have an SDOH information section that gives a simple explanation on socioeconomic influence on mortality using evidence-based information. Lastly, a technical limitation to this project was that the age-wise plot was unable to process interactivity features under the *plotly* package, which means this is the only app out of the four that does not have a hover function. Therefore, this final app used the *gridExtra* package in R to place two graphs side by side under the “both” filters to ease comparison of diagrams.

Conclusions

Four interactive Lexis diagrams were created, allowing users to visualize Canadian mortality data indicators by SDOH factors including age, sex, cause of death, and socioeconomic status. These interactive applications may serve as public health and research tools to advance resource allocation, support healthcare decision-making, inform health policy, and promote education and health literacy.

Future research should focus on the importance of Lexis diagrams and their potential to advance public health surveillance and inform health policy. Additionally, implementing automatic data updates, expanding cause of death data to include novel diseases such as COVID-19, and scaling diagrams for regional and rural surveillance, are all areas of focus that would strengthen public health preparedness. The use of live updates would permit users to see up-to-date visualizations and notify healthcare professionals of any changes to mortality trends for stronger resource allocation. Expanding visualizations like these across other Canadian cities using region-specific data would help public health agencies alert and educate vulnerable populations of any changes in health and mortality trends. Lastly, the expansion of historical data will allow for more accurate modeling of mortality trends beyond 2022, as this project does not account for changes in mortality trends between the years 2023 and 2026.

Data Sources

Public Data Sources:

Human Mortality Database (mortality.org), which includes deaths spanning from 1921 to 2022, Canadian Population data, and deaths by cause from 1950-2019. This will be used for visualization of primary mortality indicators.

Controlled-Access Data Sources:

Vital Statistics Death Database, Multiple Cause of Death File, and the Canadian Census Health and Environment Cohort (providing socioeconomic information). This will be used to visualize mortality by contributing cause of death and by key socio-economic variables.

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Access is approved through the Statistics Canada Carleton Research Data Centre.

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Appendices

Full code and data are available on GitHub via Alie-23/Mortality_Lexis_Proj