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Online Map Design for Public-Health Decision Makers

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Abstract

Injury places a heavy burden on public-health resources that is not distributed evenly in space, making the mapping of injury and its socio-demographic risk factors an effective tool for prevention planning. In a survey of health-related interactive Web mapping applications we found great variation with respect to content, cartography, and technical aspects. Based on the survey results, input from a group of potential end users, cartographic design principles, and data-set requirements, we created a Web site with static, animated, and interactive injury maps. We mapped injury rates and possible socio-demographic risk factors for the City of Toronto. Through the three functionally different types of maps, a variety of ways to explore the same public-health data sets could be demonstrated. The results highlight the practical options available to public-health analysts and decision makers who wish to expand their data-exploration and decision-support tools with a spatial component.

Keywords: cartographic design, health geomatics, injury prevention, socio-demographic risk factors, Web mapping

Résumé

Les blessures corporelles représentent un très lourd fardeau pour les ressources en santé publique. Comme ce fardeau n'est pas équitablement distribué dans l'espace, la cartographie des blessures et des facteurs de risque sociodémographiques est un outil efficace pour planifier les mesures de prévention. Dans le cadre d'un examen des logiciels de cartographie Web interactifs liés à la santé, on a noté de grandes variations pour ce qui est du contenu, de la cartographie et des aspects techniques. D'après les résultats obtenus, les renseignements fournis par un groupe d'utilisateurs potentiels, les principes de design cartographique et les exigences en matière d'ensembles de données, on a créé un site Web contenant des cartes statiques, animées et interactives sur les blessures. On a cartographié les taux de blessures et les facteurs de risques sociodémographiques possibles pour la ville de Toronto. Grâce aux trois types fonctionnellement différents de cartes, on avait recours à une variété de moyens pour explorer les mêmes ensembles de données en santé publique. Les résultats font ressortir les options les plus pratiques pour les analystes en santé publique et les responsables de la prise de décision qui veulent explorer plus en détail certaines données et utiliser les outils d'aide à la décision avec une composante spatiale.

Mots clés : design cartographique, géomatique liée à la santé, prévention des blessures, facteurs de risque sociodémographiques, cartographie Web

1. Introduction

Injury is an often-overlooked public-health issue with extensive social and economic costs to society. Previous research has identified demographic and socio-economic risk factors for injury via different mechanisms, including falls, road accidents, assaults, and self-inflicted injury (Thouez and others 1991; Tinetti and others 1994; Saunderson and Langford 1996; Cubbin and Smith 2002; WHO 2002; Macpherson and others 2005). Knowledge of the determinants of injury and the focus on at-risk populations lends itself to a geographically explicit analysis and to the use of maps to assess spatial and spatiotemporal patterns of injury and of risk factors for injury (Croner 2003; Yiannakoulias and others 2003; Hempstead 2006; MacLachlan and others 2007; Cusimano and others 2007).

Stakeholders in injury prevention and control are affiliated with different levels of government as well as with community and non-profit organizations. We developed a Web portal with different types of maps of injury rates and socio-demographic determinants of injury for the City of Toronto to provide these stakeholders with distributed access to a novel decision-support tool for data exploration and program planning. Maps are increasingly recognized as innovative and useful decision-making tools for use in public health and other domains (Driedger and others 2007).

Part 2 below reviews previous research on injury as a public-health issue. Part 3 summarizes the results of a survey of health-related interactive mapping Web sites. Based on cartographic principles, the findings of the survey, and a needs assessment with public-health stakeholders, static and animated maps as well as an interactive map application were created using injury and socio-demographic data for the City of Toronto, Ontario. Part 4 describes the online map design, and Section 5 discusses the resulting maps and provides an outlook on geovisualization and Web mapping in injury prevention and control.

2. Injury and Its Socio-demographic Determinants

Injury is a primary cause of mortality, morbidity, and disability, and is a massive burden to public health (Cubbin and Smith 2002; Segui-Gomez and MacKenzie 2003). Injury is known as the "invisible epidemic" because of its pervasiveness and the lack of resources directed toward prevention and control (CIHI 2007). Health care expenditures and indirect costs associated with injury are significant; a massive number of hospitalizations and deaths occur each year as a result of injuries. On a global scale, more than 5 million people die from injuries every year, representing 9% of total global mortality (WHO 2007). In Canada, injury is the leading cause of mortality for children and young adults and one of the primary causes of hospital visits for children, young adults, and seniors (Health Canada 2007). The annual social and economic burden of injury for Canada is highlighted by the following figures for the year 2002 (CIHR 2007):

- 2 million injuries sustained
- 14,000 deaths
- 250,000 hospitalizations
- $12.7 billion in resulting costs (including indirect costs)

On average in the province of Ontario, someone visits an emergency department every 30 seconds, and someone is hospitalized every 10 minutes, as a result of injury (Macpherson and others 2005). Injury has therefore increasingly become a target of national and global prevention and control programs.

Injuries have a variety of causes, including falls, road accidents, and assaults as well as self-inflicted injuries. Ultimately, everyone is at risk of injury; nevertheless, the burden of injury lies disproportionately within some sectors of society. There is thus a need for population-based injury research to elicit strategies to target specific at-risk groups, with the aim of reducing the burden of injury (Macpherson and others 2005).

Reducing the occurrence of any mortality or morbidity phenomenon requires knowledge of its determinants (Saunderson and Langford 1996). Socio-economic status is known to affect the distribution of injury in society; indeed, it is considered a fundamental determinant of human health in general (Cubbin and Smith 2002). Socio-demographic determinants of injury include age, level of education, socio-economic status, employment status, and occupation. For example, fall-injury rates are highest in the infant and elderly age groups, while rates of both motor-vehicle injury and assault are highest among youth and young adults (Thouez and others 1991; Tinetti and others 1994; WHO 2002). Globally, suicide rates are three times higher in the 75+ age group than in the 15–24 age group (WHO 2002).

Geography is an intrinsic aspect of public health (PHAC 2007) and can contribute to decision making in health-related planning, prediction, and prevention. Information on the spatial aspects of health issues is increasingly seen as vital for health planners (Croner 2003). A recurrent focus of public-health investigations is to examine how health outcomes vary spatially (Yiannakoulias and others 2003). Mapping of health and census data can help reveal associations between the two and highlight location-specific risk factors.

A study by Katherine Hempstead (2006) examined geographic patterns of attempted and completed suicides in New Jersey and compared them with patterns of socio-demographic determinants for suicide. Their results suggest that patterns of attempted and completed suicides varied spatially, coinciding with certain socio-demographic characteristics. John MacLachlan and others (2007) document the production phase of a Web-based interactive mapping tool created to investigate the relationship among asthma, air quality, and socio-demographic factors in Hamilton, Ontario; they describe how interactive Web mapping can provide geographic information systems (GIS) technology to public-health professionals and community groups at a very low cost. In addition, online maps can be designed to be easy to use even for users who have no prior experience with GIS. For research on injury prevention and control, GIS has the potential to inform us about social and physical determinants of injury through information related to the site of injury or the victim's place of residence (Cusimano and others 2007).

3. A Survey of Health-Related Interactive Web Mapping

3.1 MAPS AND THE INTERNET

Within geography, maps are increasingly used for data exploration and visual analysis, in addition to presenting analysis results (DiBiase 1990; MacEachren 1994; Rinner 2007). Geovisualization research focuses on determining new ways to display geographically referenced data. The objective is to enhance decision-support tools by facilitating the recognition of spatial patterns and spatiotemporal trends.

Web-based maps have become omnipresent in recent years, mirroring the advancement of desktop GIS and information technology in general. Three functionally different types of maps – static, animated, and interactive – are found on the Internet (Peterson 2003).

Static maps are non-modifiable representations of geographic phenomena that can be viewed onscreen or printed. The functionality of static maps is similar to that of traditional paper maps.

The potential for *animated mapping* has grown enormously with the increasing use of computers and the improvements in geographic information technology in recent decades (Harrower 2004). Animating a series of maps can be useful for detecting similarities or differences in spatial distributions. This map type is effective for representing dynamic geographical phenomena through the interrelations of location, attribute, and time (Ogao and Kraak 2002). Both temporal and non-temporal spatial data can be animated. Temporally animated maps can show change over years, months, days, or hours. Michael Peterson (1994) describes some uses of non-temporal animations, including the variation of data classification for choropleth maps and the depiction of a series of variables related to a common subject. Whether temporal or non-temporal, the principal goal of cartographic animation is to highlight change (Peterson 1994). A study by Amy Griffin and others (2006) found that animated time-series maps are more effective than a display of multiple static maps for the same time series in facilitating a person's recognition of spatial clusters.

Interactive maps allow for user interaction through manipulation of the visual display. Interactive maps range from simple place-locating and route-finding applications such as Google Maps or MapQuest to Web-based GIS applications of varying complexity. Web-GIS applications range from maps whose sole interactive function is zoom manipulation to multi-function applications with near-desktop GIS capabilities. The massive growth of map distribution via the Internet is attributed chiefly to the growth of Web-based interactive maps (Peterson 2003; Kraak 2004).

3.2 COMPARISON OF INTERACTIVE HEALTH-RELATED MAPPING WEB SITES

A survey was undertaken to determine the uptake, use, and functionality of online mapping technology in public-health applications. At the time of the survey, in November 2006, the number of English-language Web sites devoted solely to mapping health data was limited, and many of these sites were password-protected and thus inaccessible. As a result, some sites included in the survey were not entirely devoted to mapping health data, though some human-health-related content was a requirement for inclusion.

Based on the above discussion of the influence of interactive Web mapping on the broader use of maps, an interactive mapping component was a requirement for all sampled sites. This inclusion criterion was also chosen because considerable variation was found among the interactive maps, while the static maps available on health Web sites were similar in style and functionality, and because there were not enough sites with animated maps to perform a valid survey.

In addition, variation in the type of organization providing the applications was sought; the sample therefore included Web sites from both non-governmental and government organizations. Finally, the sample included Web sites for organizations at different geographic scales, including the global, the national, and the subnational. All these sampling criteria were chosen in an effort to ensure variation between the surveyed sites, in order to illuminate the various possibilities for developing Web-based maps for injury prevention.

The health-related mapping Web sites were evaluated based on the following assessment categories, modified from a study by MacLachlan and others (2007), who have demonstrate their importance for Web-GIS comparisons:

- Metadata
- Data
- Cartography
- Technical aspects

The *Metadata* criterion compared the currency of the data used in the Web-GIS tools surveyed. Criteria in the *Data* category assessed whether the underlying data were accessible to the user, while the *Cartography* criteria examined functionality and display options. The *Technical Aspects* criteria were included in order to compare the overall usability of the Web-GIS tools and of the software used for development.

The following sites were surveyed in November 2006 and were last visited in August 2007:

- British Columbia Centre for Disease Control – Interactive GIS Mapping for West Nile Virus (http://maps.bccdc.org/)
- US Centers for Disease Control and Prevention (CDC) – National Center for Injury Prevention and Control (http://www.cdc.gov/ncipc/maps/)
- Public Health Agency of Canada (PHAC) – Injury Surveillance Online (http://dsol-smed.phac-aspc.gc.ca/dsol-smed/is-sb/m_prov_e.phtml)
- World Health Organization (WHO) – Global Health Atlas (http://www.who.int/globalatlas/)
- The Atlas of Canada – Health (http://atlas.nrcan.gc.ca/site/english/maps/health)
- National Cancer Institute – Cancer Mortality Maps and Graphs (http://cancercontrolplanet.cancer.gov/atlas/index.jsp)
- US Geological Survey – Interactive Avian Influenza Maps (http://www.nwhc.usgs.gov/disease_information/avian_influenza/avian_influenza_maps.jsp)
- Net Aid Interactive Map Series (http://www.myriadeditions.com/netaid/indexF.htm)
- Globalis: An Interactive World Map (http://globalis.gvu.unu.edu/)
- EpiScan GIS – Meningococcal Disease Surveillance in Germany (http://episcangis.hygiene.uni-wuerzburg.de/Locale.do?language=en)

Table 1 shows the results of the survey. Large variations existed between sites with respect to data currency: three sites had data current within the past year, while the data on the remaining sites were between three and 12 years old. Most sites (7/10) allowed for printable maps, while only two had downloadable data available.

The cartographic functionality also varied greatly among the 10 sites. Just two allowed for a change of colour scheme. A majority, eight, used the choropleth method to display data. Every site allowed for an interactive change of the type of health condition being displayed, apart from the three that focused on just one condition. Six sites had some sort of time-series change functionality, varying from comparisons of different time ranges to simple year-over-year comparisons. Socio-demographic data were available for analysis or comparison with the health data on five of the sites, and four sites allowed for interactive overlay of these data on top of the health-data layer. Only the BC West Nile interactive tool had advanced analysis tools, including buffering, table queries, and multiple layer overlays. The other sites were chiefly restricted to simple interactions such as panning, zooming, and simple overlays. The geographic area available for mapping varied from regional (county, health region, sub-provincial) to international scales. Four sites offered the choice of more than one geographic scale; none allowed for analysis below the regional scale.

The Technical Aspects category proved the hardest to quantify, because the performance of Web mapping applications depends on independent factors including the Internet connection, traffic intensity, data efficiency, and the capacity of both client-side and server-side machines (Kraak 2004). The sites rated as easy to interpret were Atlas of Canada, USGS Avian Influenza, and EpiScan GIS; those rated as difficult to interpret were Globalis and BC West Nile. Six Web sites were considered easy to use; only BC West Nile was assessed as fairly difficult to use, perhaps because of its sophistication, as described above. Six different Internet map-server software products were used for the Web sites surveyed; the two most common were ArcIMS by ESRI Inc. and the University of Minnesota MapServer, each powering three of the interactive health-mapping applications. Redraw times were determined subjectively through several site visits from different computers during the survey period. A wide variation in redraw times was found among the interactive mapping tools. Redraw times were slower for

Table 1. Results of a survey of interactive health-related mapping Web sites

	BC West Nile	CDC Injury Control	PHAC Injury Surveillance	WHO Global Health Atlas	Atlas of Canada	US Cancer Maps (NCI)	USGS Avian Influenza	Net Aid	Globalis	EpiScan GIS
Metadata										
Most current data	2005–2007	1998	2001	2001	Various	1994	2007	Various	2003	2007
Data										
Printable maps	Yes	Yes	No	Yes	Yes	Yes	No	No	Yes	Yes
Downloadable data	No	Yes	Yes	No	No	No	No	No	No	No
Cartography										
Change colour scheme	No	Yes	No	No	No	Yes	No	No	No	No
Data display type	Symbol	Choropleth	Choropleth	Choropleth	Choropleth	Choropleth	Symbol	Choropleth	Choropleth	Choropleth/Symbol
Change condition type	No	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	No
Change time period	Yes	No	Yes	Yes	No	Yes	No	No	Yes	Yes
Socio-demographic data	No	No	No	Yes	Yes	No	No	Yes	Yes	Yes
Data overlay	Yes	Yes	No	Yes	No	No	No	No	Yes	Yes
Simple/advanced analysis tools	A	S	S	S	S	S	S	S	S	S
Geographic scale	Regional	National/state/county	Provincial/regional	International	National/regional	State	National	International	International	State/county
Technical Aspects (1 = easy, fast; 5 = difficult, slow)*										
Ease of interpretation	4	2	2	3	1	2	1	2	5	1
Ease of use	4	1	1	1	1	2	2	1	2	1
Redraw time	3	3	1	4	2	3	3	1	3	1
Software used	ArcIMS	MapInfo	MapServer	ArcIMS	MapServer	OptiMap	Google Maps	MXI	ArcIMS	MapServer

*Rated subjectively on a five-point scale all the ArcIMS-powered sites than for those powered by MapServer.

4. Design of Online Maps for Injury Prevention

4.1 NEEDS ASSESSMENT AND DATA PREPARATION

Web maps should be designed according to the abilities and requirements of the intended user group. Recent studies have described the need to obtain user input when designing Web-based maps for use in public health (e.g., Bhowmick and others 2008; Driedger and others 2007). In the course of this project, a series of meetings with public-health stakeholders and injury-prevention advocates illustrated the need for maps and data-visualization tools to examine spatial patterns of injury and related socio-demographic determinants. More in-depth discussion with individuals in this user group highlighted a need for tools that are simple and easy to use, and thus accessible to a wide range of analysts and decision makers. This user input provided the founding guidelines for the design and development of the online maps.

Based on user recommendations, data on both injury and socio-demographic determinants of injury were included. Injury data for Toronto were obtained from the Ontario Trauma Registry's (OTR) Minimal Data Set (MDS) for the three-year period from 2001 to 2003. OTR MDS data are collected and recorded as injury-related hospitalizations by place of residence. Injuries tend to be categorized into two sub-fields: intentional and non-intentional (Cohen and others 2003). We further broke down the non-intentional injuries into three categories of common injury types (1) *fall*, (2) *motor vehicle and traffic*, and (3) *other* injuries. Intentional injuries (assaults, homicides, suicide, and self-inflicted injuries) were kept as a meta-category, because fewer incidents were recorded in the OTR data set, and thus aggregation was necessary to ensure privacy of individual records. *Other* injuries were non-intentional injuries that did not fall into either of the other two classes. The injury counts were aggregated to the level of the three-digit Canada Post Forward Sortation Area (FSA), an areal unit of varying size, of which there were 102 in the City of Toronto during the study period. FSA units with fewer than five injury counts were excluded for reasons of privacy protection.

Socio-demographic data were taken from the 2001 national census, collected by Statistics Canada and delineated by FSA. The variables of interest were extracted from the following demographic categories:

- Age
- Education
- Income
- Employment status
- Occupation

The socio-demographic data were converted into proportions to allow for choropleth mapping and areal comparisons. The injury variables were standardized as a rate per 100,000 based on 2001 population counts.

4.2 CARTOGRAPHIC DESIGN PRINCIPLES

Designing maps for use in public health poses unique challenges related to potential users' ability to interpret spatial data, colour schemes, and other aspects of map design. Ultimately, map creation must be based on users and their capabilities, the situation, and the purpose of the map.

Map data are often aggregated into classes as a means of simplifying the visual effect and to assist comprehension (Krygier and Wood 2005). Classified choropleth (area-shaded) maps are often used to represent health data in an effort to protect the privacy of the individual. There are several common methods for data classification, including equal intervals, quantiles, natural breaks, and optimal classifications (e.g., Slocum and others 2005). The choice of method varies by need and by data type, as well as according to rules about data confidentiality. The quantiles method places an equal number of area units into each class. This method has traditionally been used in epidemiological rate mapping and was confirmed to be the best classification method for choropleth maps of epidemiological data in a study by Cynthia Brewer and Linda Pickle (2002). For easier comprehension by inexperienced end users, it is commonplace to round off the class breaks aggressively to simplify the legend.

A correct colour scheme is fundamental to the accurate portrayal of the visual implications of data in choropleth maps. For data that are unipolar (progressing from low to high), a *sequential* colour scheme – an increasingly darker shade for each class – should be used (Brewer and Pickle 2002). Bipolar data should use a *diverging* colour scheme, in which two increasingly darker hues diverge from a central light hue (Slocum and others 2005). The choice of a valid colour scheme depends on data type, map user, and display hardware. The same colour scheme and classification method should be used for all maps in a series (Brewer 2001).

4.3 THE TORONTO INJURY MAP PORTAL

A Web portal for injury-related maps was created for eventual access by public-health stakeholders. The site was initially password-protected, to address privacy concerns around the injury data sets. A screenshot of the homepage is shown in Figure 1. A partial version of the Web portal is accessible at <http://141.117.104.183/toronto_injury/> (user name "cartographica"; password "injurygis"). For reasons of confidentiality, maps of injury data could not be included in this version.

Figure 1. Screenshot of the prototype Toronto injury map portal (a partial version is viewable at http://141.117.104.183/toronto_injury/).

Three types of maps (static, animated, and interactive) were then created for the same injury and socio-demographic data, to allow injury-prevention stakeholders to choose the type best suited to their needs, purpose, and level of expertise. For example, Terry Slocum and others (2004) found that study participants considered animated and static maps suitable for different tasks: animated maps for examining general trends, and static maps for comparing specific time points.

4.4 DESIGN OF STATIC MAPS

The design of the static maps was informed by the cartographic standards outlined above. Choropleth maps of injury and socio-demographic determinants of injury were created using ESRI's ArcGIS 9.1. The quantiles classification method was used to create a five-class map. All maps use a sequential colour scheme with dark red symbolizing the direction of the data indicating concern (high injury rates, low average income, etc). This scheme was chosen using the ColorBrewer tool (Brewer 2002). According to ColorBrewer, this scheme is more suitable for display on laptop LCD and traditional CRT screens than for printing, which seems acceptable for Web-based maps. Table 2 lists the series of static injury and socio-demographic maps.

Figure 2 is an example of the static injury maps, showing fall-injury incidence per 100,000 residents for Toronto by FSA; Figure 3 is a static socio-demographic map showing the proportion of the 65+ age group by FSA. These maps have simplified legends because class breaks have been rounded off; they were designed to be easy to use and understand, so as to appeal to users in public health regardless of their map-reading expertise. The static

Table 2. Themes of static maps.

Injury (rate per 100,000)	Socio-demographic Risk Factors
Fall	Age 15–24 (%)
Motor vehicle/ traffic	Age 65+ (%)
Intentional	Average household income ($)
Other	Low-income households (%)
All injuries 2001	Unemployment rate (%)
All injuries 2002	Blue-collar workers (%)
All injuries 2003	Residents without high school diploma (%)
All injuries	Residents with university degree (%)
2001–2003	Population density (people/km^2)
(mean)	Major streets

maps can be downloaded and printed from the Web site as PDF files and used in analysis and collaboration by viewing them onscreen, adding them to presentations, or viewing the printed versions.

4.5 DESIGN OF ANIMATED MAPS

The static maps were converted into GIF (Graphics Interchange Format) files and combined into single animation files using Jasc Animation Shop 3.01. Four animated maps were produced; these are listed in Table 3 with an explanation of the content, the number of frames in the animation, and the frame delay used in each.

Figure 4 shows the frame layout for an animation of all injuries by year, 2001 to 2003. The speed of the animations was varied depending on how different each frame is from the preceding frame (see Table 3); this particular animation was configured with a frame delay of two seconds, as all frames show the same variable (total injuries) and only the year changes between frames. The animations of injury types and injury determinants had a frame delay of three seconds to allow viewers to comprehend the new variable introduced in each frame. The animated map files are available to view onscreen from the Web portal, using the login information given above; users can click on a link that automatically starts each animation. These maps would most likely be used by an individual, although it would be possible to use them for presentations and collaboration by navigating to the Web site to view the animation.

4.6 DESIGN OF INTERACTIVE MAPS

A prototype of an interactive map tool was created using UMN MapServer, an open-source online mapping environment developed at the University of Minnesota. MapServer can be installed easily via the MS4W (MapServer for Windows) package, which is free to download from DM Solution Group's MapTools Web

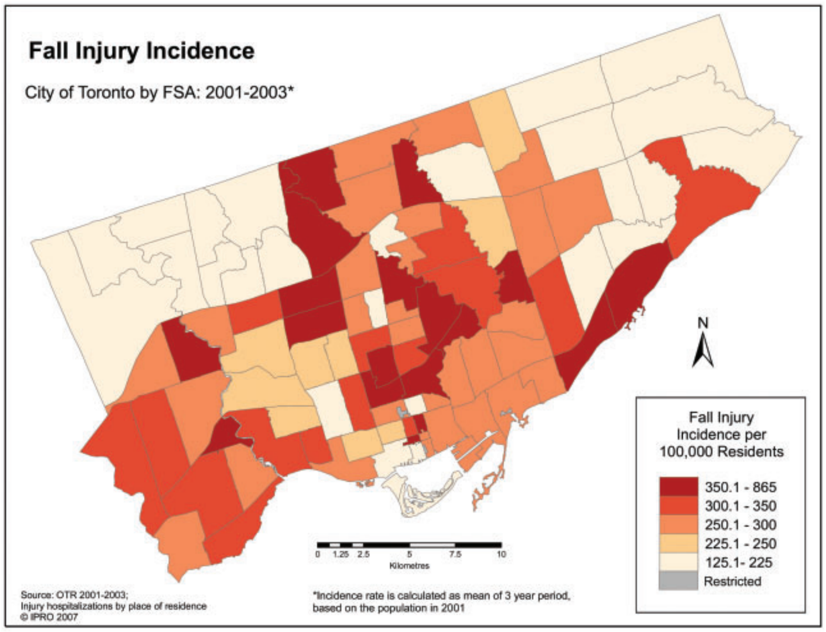

Figure 2. Static map of fall-injury incidence in Toronto by FSA.

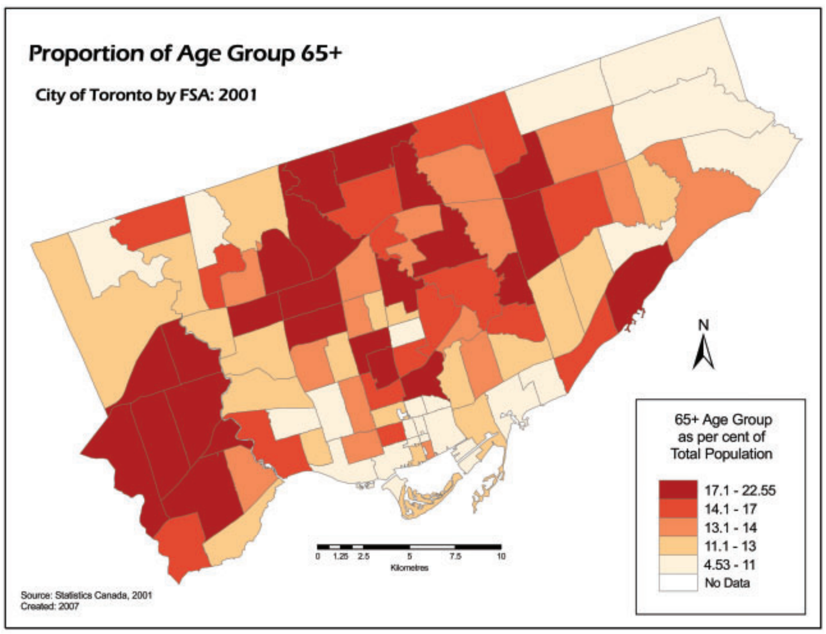

Figure 3. Static map of proportion of population age 65 and older in Toronto by FSA.

Table 3. Themes of animated maps

Animated Map Title	Explanation	Frames	Speed
All Injuries by Month	12 months	12	2 sec/frame
All Injuries by Year	3 years	3	2 sec/frame
Injury Type	4 injury types	4	3 sec/frame
Injury Determinants	8 socio-demographic risk factors	8	3 sec/frame

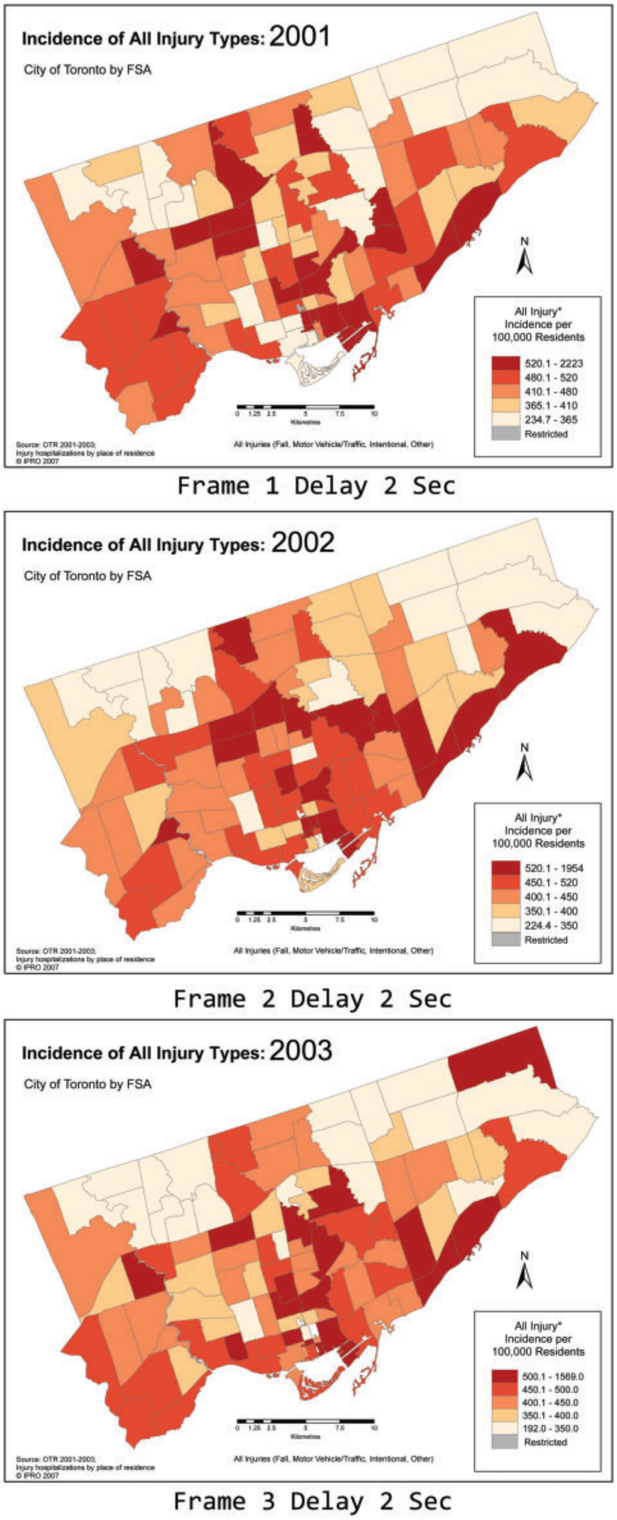

Figure 4. Frame layout of the animated map of all injuries by year (animations can be accessed at http://141.117.104.183/toronto_injury/).

site. The main purpose of the interactive map tool was to allow users to compare spatial patterns of injury with spatial patterns of associated risk factors, a feature requested by potential end users during the needs assessment. Therefore, it was decided that the interactive tool should allow for comparison of two maps on a single screen. This goal was accomplished by splitting the screen into two horizontal frames, each containing an interactive map.

The development of the interactive injury-mapping tool was largely informed by the findings of the Web site survey. Variations in the design of this tool from the results of the survey are largely attributable to restrictions placed on the injury data set and to the need for a greater focus on map comparison, as requested by the potential user group. The cartographic design used for the static and animated maps was also used for the interactive maps, to ensure similar patterns and a similar visual effect across all map types. Figure 5 is a screenshot of the interactive map tool, with the map of fall-injury rates and the map of population aged 65 and over displayed. The top map is set at full map extent, while the bottom map is zoomed in twice, with the road layer overlaid on top.

Several of the surveyed sites included some form of socio-demographic data for comparison, though not to the extent offered in this application. The tool described here was envisioned to allow for full data comparison of any two injury and/or socio-demographic maps. For example, an analyst could compare the fall-injury map with the map of age group 65 and over or compare spatial patterns of fall injuries with those of intentional injuries. Although many of the sites surveyed used some form of overlay to support comparison, for this project it was decided to minimize data overlay to avoid obscuring spatial patterns. Instead, a split-screen viewing window with two drop-down menus was devised to allow for any combination of two maps to be displayed simultaneously and compared. A major roads layer, intended to aid the map reader's recognition of specific geographic areas, is the only overlay used in the interactive map tool.

The choropleth legend classes in the interactive tool were created with the same class breaks as the static and animated maps, to ensure that the map patterns were the same across map types. Users were not given the option to modify the map's colour scheme, because this option was available in only two of the tools surveyed and therefore not deemed necessary. The choropleth mapping technique was used because it was the most common map type used in the surveyed sites and because it is appropriate for visualizing injury rates.

The most current injury data set available for inclusion with this interactive map tool was for 2003, which was considered acceptable because it matched or bettered the data currency of many of the sites examined in the survey. All maps used in the tool are downloadable as static PDFs map files, stored on another page of the Web site. A majority of the surveyed sites offered printable maps, though not all were easily downloadable; the results of

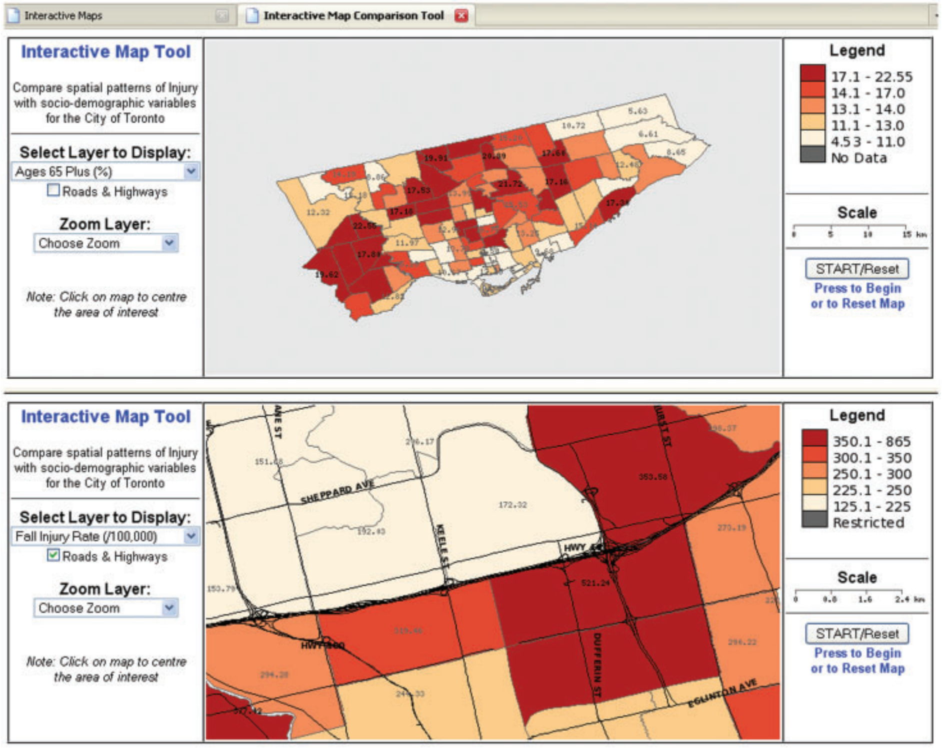

Figure 5. Screenshot of the interactive mapping tool.

the needs-assessment meetings suggested that the Toronto injury site should be simple and easy to use, and easily downloadable and printable maps were therefore a necessity. The raw data are not accessible because of restrictions on the data sets; most of the sampled sites also did not make their raw data accessible. The UMN MapServer software was chosen because it protects the raw data by sending server-generated images of the mapped data to the client computer rather than transmitting the data themselves. It also was the most common software used on the surveyed sites, along with ArcIMS; however, all the sites powered by MapServer were quicker to redraw. Further, MapServer offers suitable functionality and is free to use, whereas use of ArcIMS requires a high licensing fee.

Simple functionality was chosen for this tool to reflect the findings of the survey (most sites had simple functionality) and to make the tool more appealing to the inexperienced user. The interactive tool includes zoom functionality, operated by choosing fixed "zoom in" or "zoom out" options from a drop-down menu. The maps can be re-centred by clicking anywhere on the map, or the user can start over again with the default map at full extent by clicking the "Start/Recentre" button. Subjectively, this mapping tool ranks with the easiest of all the sites to interpret and to use. This tool was created at the scale of a municipality, a much finer spatial resolution than is used in any of the interactive maps included in the survey.

5. Discussion and Conclusion

Static, animated, and interactive maps of injury and socio-demographic determinants of injury were designed and made available through a Web portal. These maps were created on the basis of a needs assessment provided by a group of potential end users in injury prevention; principles of cartographic design, a survey of health-mapping Web sites, and requirements related to the data sets also informed many of the design elements. The creation of three map types underscores the notion that individual knowledge and preferences, as well as differing circumstances, will dictate the type of map that is appropriate to address a task. The maps resulting from this study can be used in decision support for injury prevention and control in Toronto. The cartographic and Web-mapping standards described in the study can be used by public-health organizations to develop or expand their spatial decision-support portfolios.

It is believed that each type of map will be useful in different circumstances, a notion suggested by Terry Slocum and others (2004) based on a map-use test comparing static and animated maps. For example, the static maps will likely be most useful for collaboration (through the ability to print) and as visual aids in presentations. The animated maps, particularly the time-series versions, may be most appropriate for health planners analysing rate changes over time for particular areas within the city. The interactive map tool is likely the most versatile, although it may appear more complex to potential users than the static and animated maps.

Further research should examine the utility of displaying data using multiple techniques in order to advance geovisualization and Web-based mapping in the search for improved methods of data display and decision support. A logical step forward in this research is to test the map types with potential users. An ongoing user test with public-health stakeholders will help to determine the usability of each map type and its utility for injury prevention and control. A more detailed study might centre on the design of variants of the interactive mapping tool with varying degrees of data and functionality. Another area of investigation concerns the costs associated with implementing and maintaining online health map sites, as discussed by Qian Yi and others (2008). While the use of an open-source Internet map server package drastically reduced the licensing costs in this study, there may be other costs related to development and maintenance that will depend on factors such as the popularity of a tool and the availability of technical support.

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