**Steps in Transforming the Missouri Cancer Registry (MCR) from an
Incidence Registry to a Survival Registry:**

Estimate and Interactively Visualize Female Breast Cancer Burden in Missouri Senatorial
Districts and Assess the Usability of the Missouri Cancer Registry and Research Center's (MCR-
ARC's) Published Interactive Maps

A Dissertation

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By

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To the souls of my amazing dad and a wonderful mom

To my beloved husband Lutfi

To my precious treasures Razan, Rian, Mariam, and Ahmad

They are the reason for who I am today

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TABLE OF CONTENTS

ACKNOWLEDGMENTS.....	ii
LIST OF ILLUSTRATIONS.....	viii
LIST OF TABLES.....	xii
LIST OF ACRONYMS.....	xv
ABSTRACT	xviii
CHAPTER	
I. Introduction.....	1
II. Estimate Female Breast Cancer Burden inn Missouri Senatorial Districts and Improve Visualization of the Obtained Results Using Data Visualization Software.....	6
Estimate and Visualize Female Breast Cancer Incidence Rates in Missouri Senatorial Districts in Interactive Mapping Formats (2008-2012)	7
Abstract.....	7
Introduction.....	8
Methodology.....	9
Results.....	11
Discussion.....	22
Conclusion.....	26
References.....	28

Estimated Female Breast Cancer Mortality-to-Incidence Ratio (MIR) of the Counties and the Senatorial Districts Grouped to County Boundaries (SDGCS) in Missouri (2008-2012).....	35
Abstract.....	35
Introduction.....	35
Methodology.....	38
Results.....	41
Discussion.....	48
Conclusion.....	50
References.....	51
Estimate Female Breast Cancer Survival in Missouri Senatorial Districts and Improve Visualization of the Obtained Results Using Interactive Mapping Reports (2004-2010).....	59
Abstract.....	59
Introduction.....	60
Methodology.....	63
Results.....	67
Discussion.....	78
Conclusion.....	83
References.....	85
III. Assess the Usability of the Missouri Cancer Registry and Research Center’s (MCR-ARC’s) Published Interactive Maps and Profile Reports.....	90

Geographic Information Systems: Usability, Perception, and Preferences of Public

Health Professionals.....	91
Abstract.....	91
Introduction.....	92
Methodology.....	94
Results.....	96
Discussion.....	108
Conclusion.....	110
References.....	111

Usability Assessment of the Missouri Cancer Registry's Published Interactive

Mapping Reports: Round One.....	115
Abstract.....	115
Introduction.....	116
Methodology.....	119
Results.....	124
Discussion.....	134
Conclusion.....	139
References.....	141

Usability Assessment of the Missouri Cancer Registry's Published Interactive

Mapping Reports: Round Two.....	147
Abstract.....	147

Introduction.....	148
Methodology.....	150
Results.....	155
Discussion.....	167
Conclusion.....	173
References.....	175
APPENDICES	179
Appendix A: Creation of Senate District Population File (2008-2012)..	180
Appendix B: Usability Testing Questionnaire.....	183
Appendix C: Multi-task Test Scenario.....	185
Appendix D: SUS Scale for Testing MCR-ARC Mapping Reports.....	188
Appendix E: Usability Trial’s Recruitment Email.....	190
VITA.....	191

LIST OF ILLUSTRATIONS

CHAPTER II

Estimate and Visualize Female Breast Cancer Incidence Rates in Missouri Senatorial Districts in Interactive Mapping Formats, 2008-2012

FIGURE	PAGE
Figure 1: Area Profile Interactive InstantAtlas™ Report Displaying Female Breast Cancer (FBC) Incidence Data by Senatorial District	16
Figure 2: Double Map Interactive InstantAtlas™ Report Displaying Female Breast Cancer (FBC) Incidence by Senatorial District	17
Figure 3: Female Breast Cancer (FBC) Incidence Data by Age for Senate District 19 and Missouri	18
Figure 4: Female Breast Cancer (FBC) Incidence Data by Race for Senate District 19 and Missouri	18
Figure 5: Female Breast Cancer (FBC) Incidence Data by Stage and Grade Percentages for Senate District 19 and Missouri.....	19
Figure 6: Female Breast Cancer (FBC) Incidence Data by Age for Senate District 19 and Combined Districts 20 & 30.....	20

Figure 7: Female Breast Cancer (FBC) Incidence Data by Race for Senate District 19 and the Combined Districts 20 & 30.....	21
--	----

Figure 8: Female Breast Cancer (FBC) Incidence Data by Stage and Grade Percentages for District 19 and the Combined Districts 20 & 30.....	21
--	----

Estimated Female Breast Cancer Mortality-to-Incidence Ratio (MIR) of the Counties and the Senatorial Districts Grouped to County Boundaries (SDGCS) in Missouri (2008-2012)

FIGURE	PAGE
Figure 1: Area Profile Mapping Report of 65+ Female Breast Cancer (FBC) Incidence Rates by Senate Districts Grouped to County Boundaries (SDGCS) in Missouri	42
Figure 2: Area Profile Mapping Report of Female Breast Cancer (FBC) Mortality Rates of Whites by Senate Districts Grouped to County Boundaries in Missouri	43
Figure 3: Double Map InstantAtlas™ Report of 65+ Female Breast Cancer (FBC) Incidence and Mortality Rates by Senate Districts Grouped to County Boundaries (SDGCS) in Missouri	44

Estimate Female Breast Cancer Survival Data in Missouri Senatorial Districts and Improve Visualization of the Obtained Results Using Interactive Mapping Reports (2004-2010)

FIGURE	PAGE
Figure 1: Area Profile Interactive Report Displaying FBC 5-Year Cause-specific Survival Data by Senatorial District.....	72

Figure 2: Double Map Interactive Report Displaying FBC 5-Year Cause-specific Survival Data by Senatorial District.....	73
Figure 3: FBC Survival Data by Age for Senate District 19 and Missouri	74
Figure 4: FBC Survival Data by Race for Senate District 19 and Missouri	74
Figure 5: FBC Survival Data by Stage and Grade at Diagnosis for Senate District 19 and Missouri	75
Figure 6: FBC Survival Data by Age for Senate District 19 and the Combined Districts 20 & 30	76
Figure 7: FBC Survival Data by Age for Senate District 19 and the Combined Districts 20 & 30	77
Figure 8: FBC Survival Data by Stage and Grade at Diagnosis Percentages for Senate District 19 and Combined Districts 20 & 30	77

CHAPTER III

Geographic Information Systems: Usability, Perception, and Preferences of Public Health Professionals

FIGURE	PAGE
Figure 1: Search Strategy Flow Chart.....	95

**Usability Assessment of the Missouri Cancer Registry’s Published Interactive
Mapping Reports: Round One**

FIGURE	PAGE
Figure 1: Task Completion Rate (TCR) per Participant	125
Figure 2: Task Completion Rate per Task	126
Figure 3: Time-based Efficiency (TBE) per Task	128
Figure 4: Overall Relative Efficiency (ORE) per Task.....	129
Figure 5: System Usability Scale (SUS) Scores of Study Participants.....	130

**Usability Assessment of the Missouri Cancer Registry’s Published Interactive
Mapping Reports: Round Two**

FIGURE	PAGE
Figure 1: Task Completion Rate for All Tasks per Participant.....	157
Figure 2: Task Completion Rate per Task for All Participants.....	158
Figure 3: Time-based Efficiency (TBE) per Task	161
Figure 4: Overall Relative Efficiency (ORE) per Task	162
Figure 5: System Usability Scale (SUS) Scores of Study Participants	163

LIST OF TABLES

CHAPTER II

Estimate and Visualize Female Breast Cancer Incidence Rates in Missouri Senatorial Districts in Interactive Mapping Formats (2008-2012)

TABLE	PAGE
Table 1: Female Breast Cancer (FBC) Incidence Rates across Different Age Groups of Females in Missouri	11
Table 2: Female Breast Cancer (FBC) Incidence Rates among White and African American in Missouri	12
Table 3: Incidence Rates of All Malignant, High Grade, and Late Stage of Female Breast Cancer (FBC) in Missouri	14

Estimated Female Breast Cancer Mortality-to-Incidence Ratio (MIR) of the Counties and the Senatorial Districts Grouped to County Boundaries (SDGCS) in Missouri (2008-2012)

TABLE	PAGE
Table 1: Senate Districts Grouped to County Boundaries (SDGCS) and Counties	39
Table 2: Female Breast Cancer (FBC) Mortality-to-Incidence Ratio (MIR) and the MIR 95% Confidence Intervals by SDGCS and Age in Missouri	45

Table 3: Female Breast Cancer (FBC) Mortality-to-Incidence Ratio (MIR) and the MIR 95% Confidence Intervals by SDGCS and Race in Missouri	46
--	----

**Estimate Female Breast Cancer Survival Data in Missouri Senatorial Districts and
Improve Visualization of the Obtained Results Using Interactive Mapping Reports
(2004-2010)**

TABLE	PAGE
Table 1: 5-Year Cause-specific Survival Data of Female Breast Cancer (FBC) across Different Age Groups of Females in Missouri	67
Table 2: 5-Year Cause-specific Survival Data of Female Breast Cancer (FBC) among White and African-American Women	68
Table 3: 5-Year Cause-specific Survival Data of All Malignant (Excluding In Situ but Including Un-Staged FBC Cases), In Situ and Local, and Regional and Distant Categories of FBC in Missouri	69
Table 4: 5-Year Cause-specific Survival Data of Low- and High- Grade Categories of FBC in Missouri	71

CHAPTER III

**A Scoping Review: Geographic Information Systems: Usability, Perception, and
Preferences of Public Health Professionals**

TABLE	PAGE
Table 1: Usability Testing Studies Based on Testing GIS Tools by Participants.....	97

Table 2: Usability Studies Based on Interviewing the Participants.....	102
--	-----

Usability Assessment of the Missouri Cancer Registry’s Published Interactive

Mapping Reports: Round One

TABLE	PAGE
Table 1: Time on Study Tasks	127
Table 2: Demographic and Previous Expertise Factors of the Study Participants vs. the Trial’s TCR and SUS Scores.....	132
Table 3: Correlation between Studied Usability Elements	133

Usability Assessment of the Missouri Cancer Registry’s Published Interactive

Mapping Reports: Round Two

TABLE	PAGE
Table 1: Time on Study Tasks	160
Table 2: Demographic and Previous Expertise Factors of the Study Participants vs. the Trial’s TCR and SUS Scores	165
Table 3: Correlation between the Studied Usability Elements	166

LIST OF ACRONYMS

ACS: American Community Survey

BRFSS: Behavioral Risk Factor Surveillance System

CBF: Cartographic Boundary File

CCCP: Comprehensive Cancer Control Program

CDC: Centers for Disease Control and Prevention

CI: Confidence Interval

CSR: Cancer Statistics Review

DHSS: Missouri Department of Health and Senior Services

Esri (a.k.a. Environmental Systems Research Institute): An international supplier of geographic information system software

Esri ArcMap: The central application used in ArcGIS to display and explore GIS datasets for the study area, to assign symbols, and to create map layouts for printing or publication

ESTAT: The Exploratory Spatial-Temporal Analysis Toolkit

FBC: female breast cancer

G-EX: Geo-visual Explication

GIS: Geographic Information System

HMI: Health Management and Informatics

IRB: Institutional Review Board

KC: Kansas City

MCR: Missouri Cancer Registry

MCR-ARC: Missouri Cancer Registry and Research Center

MIR: Mortality-to-incidence ratio

MPH: Master of Public Health

MSA: Metropolitan Statistical Area

NAACCR: North America Association of Central Cancer Registries

NBCCEDP: National Breast and Cervical Cancer Early Detection Program

NCHS: National Center for Health Statistics

NCI: National Cancer Institute

NDI: National Death Index

NHS: National Health Statistics

NVSS: National Vital Statistics System

OMB: Office of Management and Budget

ORE: Overall Relative Efficiency

PA-CA: Pennsylvania Cancer Atlas

PEP: Population Estimation Program

PHPs: Public Health Professionals

SDGCs: Senate districts grouped to county boundaries

SEER: Surveillance, Epidemiology, and End Results Program

SEER*Stat: Statistical software that provides a convenient, intuitive mechanism for the analysis of SEER and other cancer-related databases.

SSDI: Social Security Death Index

STL: Saint Louis

SUS: Systemic Usability Scale

TBE: Time-based Efficiency

TCR: Total Completion Rate

TIGER/Line® Shapefiles: TIGER = Topologically Integrated Geographic Encoding and Referencing; Shapefiles refers to the file format. TIGER/Line Shapefiles, a spatial extract from the U.S. Census Bureau's MAF/TIGER database, is the Census Bureau's most comprehensive dataset designed for use with GIS

ABSTRACT

Female breast cancer (FBC) is the most common invasive cancer among women of all races and ethnicities in the United States (US). We aimed to estimate FBC burden in Missouri in terms of FBC incidence, mortality and survival rates; visualize these results; and assess the usability of the Missouri Cancer Registry and Research Center's (MCR-ARC's) interactive maps.

FBC survival data were calculated from 2004 to 2010 after matching MCR's FBC cases with Missouri death records, Social Security Death Index (SSDI), and National Death Index (NDI) database. FBC incidence and mortality rates were measured from 2008 to 2012. Survival and incidence data were measured by age, race, stage and grade at diagnosis and by senate district. Mortality data was measured by age, race, and by county and senate district grouped to county boundaries (SDGCs). The rates were visualized using InstantAtlas™ software. A scoping review and a two-round usability testing study were conducted to explore perceptions of public health professionals about the use of geographic information systems and to assess the usability of the MCR-ARC's published maps.

The dissertation results could be very informative for Missouri decision makers and public health leaders. The visualized data could enhance communication between collaborators from different fields related to FBC and inform health professionals and the public.

Keywords: Breast cancer, incidence, mortality, survival, MCR, MCR-ARC, NDI, SSDI, Usability.

CHAPTER I: Introduction

Introduction

In the United States (US), about 12 percent of women will be diagnosed with breast cancer at some point in their lives [1]. Nationally, the estimated new cases of breast cancer was 14 percent of all new cancer cases and the estimated deaths from breast cancer in 2014 was 7 percent of all cancer deaths [2]. The dissertation includes three main projects.

Dissertation's Main Projects

The First Project:

The investigators measured and visualized accurate female breast cancer (FBC) incidence and survival rates through a secondary analysis of FBC cases in the Missouri Cancer Registry (MCR)'s database from 2008 to 2012 for FBC incidence and from 2004-2010 for 5-year FBC survival. They measured FBC mortality for the period 2008-2012 using mortality data from the National Vital Statistics System (NVSS) database maintained by the National Center for Health Statistics (NCHS).

Traditionally, incidence and mortality rates have been presented in data tables, a format that is easily understood by epidemiologists and statisticians, but one that does not meet the needs of all potential users of the data. Data visualization is an alternative means of portraying the burden of breast cancer at various levels (e.g., county, regional, state, etc.) There is a critical need to build accurate fact sheets in the form of interactive and dynamic map reports of the breast cancer burden at the sub-state level in Missouri.

The investigators measured breast cancer incidence, mortality and survival rates using innovative methodology. To obtain survival rates, the investigators augmented linkage with Missouri death files, obtained from the Missouri Department of Health and Senior Services (DHSS) Bureau of Vital Statistics, by linking cases with unknown vital status or cause of death following this linkage with Social Security Death Index (SSDI) and National Death Index (NDI) data; the latter is administered by the National Center for Health Statistics (NCHS). NDI is considered the best resource to obtain death status and cause of death for unmatched cases that may have been diagnosed in one state but died in another state, thereby leading to more accurate survival rates [3]. The investigators also measured FBC mortality-to-incidence ratio (MIR) to explore cancer age and racial disparities in Missouri by SDGCs. The investigators presented the dissertation's results using interactive mapping software that builds dynamic reports of maps and statistics to improve data visualization [4].

The Second Project:

The investigators also conducted a scoping review study to assess perceptions and preferences of public health professionals and policy makers about the use of geographic information system (GIS) technology in public health research and policy.

The Third Project:

The investigators assessed the usability of MCR's published interactive reports. These reports include cancer and other contextual indicators' data at the Missouri county level. The investigators chose to study the usability of MCR's published maps to assess the

need for modifying and simplifying existing maps and apply the same methodology to future MCR-designed visualized reports.

How the Three Dissertation Projects Are Related

The dissertation's three main projects are methodologically different but the three projects' outcomes are very connected. The three projects shared the same mission and vision regarding FBC in Missouri. The dissertation investigators measured the FBC burden in Missouri and visualized the results, using a specific methodology and technology, as interactive mapping reports. To make the MCR's reports, which display the most accurate cancer and other contextual results very informative and understandable to the reports' potential users, these reports should undergo extensive usability assessment and evaluation using pilot samples of those actual users. In addition to the usability study of two rounds, which was conducted for this dissertation, the investigators tried to assess the preferences and perspectives of the mapping reports' actual users in the public health field using previous GIS usability literature for the years from 2000 to 2016 to write a scoping review. By conducting the two-round usability study and the review, the investigators have had comprehensive ideas and hints on how they improve the published MCR maps' usability and they were able to anticipate the perception and the predilections of the reports' actual users.

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CHAPTER II: Estimate Female Breast Cancer Burden in Missouri
Senatorial Districts and Improve Visualization of the Obtained Results
Using Data Visualization Software

Estimate and Visualize Female Breast Cancer Incidence Rates in Missouri Senatorial Districts in Interactive Mapping Formats, 2008-2012

Abstract

Objectives: To measure and interactively visualize female breast cancer (FBC) incidence rates in Missouri by age, race, stage, grade, and senate district of diagnosis from 2008 through 2012.

Methods: The FBC cases in counties split by senate districts were geocoded. A population database was created and a database was created within SEER*Stat. The incidence rates and the 95% confidence intervals (Cis) were age standardized using US 2000 Standard Population. The U.S. Census Bureau's Cartographic Boundary Files were used to create maps showing Missouri senatorial districts. Incidence results were loaded, along with the maps, into InstantAtlas™ software to produce interactive reports. We compared District 19 and Missouri's incidence data and conducted an incidence data comparison between District 19 and the combined districts 20 & 30.

Results: The area profile and double map interactive maps, including maps, graphs, and tables for the 34 Missouri senatorial districts, were built. For all races and ages, District 19's FBC incidence rates were higher than Missouri's rates. The FBC incidence rate among women >50 years old in district 19 was higher than the Missouri rate. The FBC incidence rates for whites and African Americans were higher within District 19 than Missouri. FBC incidence for African-Americans in District 19 was significantly higher than Missouri. FBC incidence data by late stage and grade percentages for District 19 were lower than Missouri's incidence percentages. FBC cases in District 19 tended to be diagnosed *in situ* or at an early stage (i.e., local); these cases are successfully treatable and seldom proceed to FBC late stages (i.e., regional and distant).

Therefore, the incidence pool of the late-stage incidence rates was lower in District 19 than combined districts 20& 30 and Missouri. For both studied regions, FBC incidence rates did not have a consistent pattern of differences by age or race.

Conclusion: The results may provide an estimation of social inequality within the state. Results could provide clues about the impact level of coverage and accessibility to screening and health care services has on disease prevention and early diagnosis.

Keywords: Female Breast Cancer, Incidence, InstantAtlas™, Interactive Maps, Missouri, Senatorial Districts

Introduction

Breast cancer incidence rates could be increased by increasing the intensity of breast cancer screening measures and interventions. These rates might be decreased by increasing prevention measures for cancer risk factors [1].

The central cancer registry database is a high quality controlled source to estimate the epidemiological rates because it follows very strict, regularly updated measures and standards [2]. Many studies revealed that there are inequalities between cancer cases according to age, race, and stage and grade at diagnosis variables [3, 4, 5, 6, 7, 8, 9].

Numerous evidence-based studies have concluded that the use of interactive geographic mapping software could allow users to interact easily with the data sets and help to publish high quality interactive reports. Distribution of geospatial health data could help public health leaders and decision makers in designing, developing, and adopting effective and efficient strategies and programs to improve public health outcomes by targeting the heavily affected geographical areas with the visualized health event [10, 11, 12].

The aims of the current study were: 1) To measure female breast cancer (FBC) incidence rates in Missouri from 2008 to 2012 according to the FBC cases' age at diagnosis, race, and Senate District of diagnosis. 2) To visualize the measured incidence rates in InstantAtlas™ interactive mapping reports. 3) To compare spatial variances and potential disparities in incidence data between some senate districts and Missouri.

Methods

The study's design was an observational, epidemiological study. The investigators did secondary analysis of all FBC cases in the Missouri Cancer Registry (MCR) database from 2008 to 2012.

The calculated incidence rates were age-standardized using US 2000 Standard Population for comparability across regions with differing age structures. We calculated the 95% confidence interval (CI) for these rates using SEER*Stat statistical package [13]. The investigators compared the calculated Missouri demographic and geographical incidence rates using the same statistical package. The FBC cases in counties split by senate districts were geocoded to determine their district for incidence; obtaining the denominator for districts with split counties presented a challenge. The investigators used TIGER/Line® Shapefiles and TIGER/Line® Files to geocode these FBC cases [14].

Population data at the district, age, race, and year level for these cases was created by combining Census American Community Survey (ACS) and Population Estimation Program (PEP) data. A database was created in SEER*Stat, a statistical software package for analyzing cancer data. Variables were created and imported to aid analyzing MCR's FBC in SEER*Stat. The Census Bureau's Cartographic Boundary Files were used to

create maps showing Missouri counties and state senatorial districts [15]. Incidence results were loaded along with the Cartographic Boundary Files into the InstantAtlas™ software to produce interactive mapping reports that display our study's results. We will attach our interactive mapping reports to the MCR-ARC website. The interactive reports included maps, graphs, and tables for the 34 Missouri senatorial districts.

The senatorial district assignment process included all FBC cases in the MCR database diagnosed from 1996 through 2012 who were residents of Missouri at diagnosis. The final analysis and maps only included the FBC cases diagnosed from 2008 through 2012 with a known county of residence

The current article involves in detail the results for the comparison between District 19 and Missouri's incidence data, and the incidence data contrast between District 19 and the combined districts 20 & 30.

District 19 includes Columbia, which is the largest city in the Columbia Metropolitan Statistical Area (MSA). We compared the measured FBC incidence data of District 19 to the combined districts 20 & 30, which includes the city of Springfield, the largest third city in Missouri according to the 2010 US Census. The compared districts are not entirely alike in demographic structure and in rural-urban fraction. By conducting this contrast, we matched the FBC incidence data of two minor metropolitan areas in Missouri. Both areas embrace university campuses -- the University of Missouri-Columbia and the Missouri State University in Springfield -- and are mostly urban with very small rural fractions. We presumed that a large fraction of these areas' population have easy access to FBC screening services and we assumed that the diagnosed FBC cases from both cities

are cases of low grades and stages and tend to be managed and monitored for better cancer outcomes.

Statistics based on a small number of cases are suppressed to help protect confidentiality. As commonly used by MCR-ARC and other central cancer registries, a threshold of five was utilized.

We tested if the regions' differences were statistically significant by determining the overlap of the 95% CIs of the compared FBC incidence rates.

Results

The senatorial districts' incidence rates of FBC were classified, as shown in tables 1-3, along with the following variables: All malignant FBC cases, less than 50 years old FBC cases, 50-64 years old FBC cases, 65+ years old FBC cases, white race FBC cases, African-American race FBC cases, late stages FBC cases, and high grade FBC cases. The tables contain the incidence rates for all the senatorial districts and Missouri and the 95% confidence intervals of the measured incidence data for all the above-mentioned variables.

Table 1. Female Breast Cancer (FBC) Incidence Rates across Different Age Groups of Females in Missouri

Senatorial Districts	<i><50 Years Old</i>			<i>50-64 Years Old</i>			<i>65+ Years Old</i>		
	<i>Rate</i>	<i>LL</i>	<i>UL</i>	<i>Rate</i>	<i>LL</i>	<i>UL</i>	<i>Rate</i>	<i>LL</i>	<i>UL</i>
1	46.2	38.8	54.6	284.9	252.8	320.1	509.4	461.1	561.4
2	45.4	38.5	53.1	304.5	267.8	344.9	483.3	425.4	546.8
3	36.4	29.6	44.4	276.5	242.3	314.2	410.4	363.6	461.6
4	44.1	36.7	52.7	283.6	249.5	321.1	508.7	457.5	563.9
5	39.5	32.3	47.8	278.7	242.4	319.0	475.0	413.6	543.0
6	42.4	35.0	51.0	232.6	202.0	266.5	403.0	357.9	452.1

7	42.2	34.8	50.6	270.3	236.0	308.1	464.4	409.2	524.9
8	40.5	33.7	48.3	273.0	239.5	309.8	392.1	340.8	449.0
9	41.1	33.7	49.6	305.4	268.4	346.1	468.3	415.0	526.4
10	41.7	34.6	49.9	268.4	235.1	305.1	412.7	364.1	465.8
11	35.5	28.6	43.7	256.8	222.8	294.5	417.8	371.4	468.2
12	43.0	35.6	51.5	252.0	220.3	287.0	392.7	349.5	439.7
13	46.5	39.2	54.7	314.6	278.5	354.0	436.0	387.9	488.3
14	54.9	46.5	64.4	330.0	293.0	370.3	437.9	387.9	492.5
15	51.1	43.5	59.8	326.0	292.8	361.9	544.7	494.5	598.6
16	38.0	30.7	46.3	236.5	205.5	270.8	419.0	372.4	469.8
17	42.1	35.1	50.1	296.3	260.5	335.7	469.1	414.5	528.8
18	42.2	34.5	51.0	263.1	230.4	299.1	407.0	364.0	453.6
19	41.9	34.4	50.4	281.6	245.5	321.5	492.3	432.4	558.1
20	42.5	35.4	50.5	276.1	242.8	312.7	395.5	348.8	446.8
21	36.7	29.9	44.7	254.9	222.2	291.1	385.6	341.5	433.8
22	44.4	37.2	52.6	237.0	205.8	271.5	373.3	321.6	431.0
23	47.4	39.8	56.0	299.2	265.8	335.6	430.1	379.4	485.7
24	47.1	39.4	55.9	295.3	263.3	330.2	542.6	494.0	594.6
25	39.8	32.5	48.2	225.3	195.4	258.6	363.2	322.7	407.3
26	44.2	37.0	52.3	323.9	289.9	360.7	461.3	413.1	513.5
27	44.5	36.9	53.3	239.5	208.1	274.4	371.8	329.2	418.4
28	33.9	27.2	41.7	264.8	232.8	299.9	391.0	350.6	434.7
29	32.7	26.3	40.1	193.3	166.6	223.0	408.3	366.5	453.7
30	41.2	33.5	50.2	292.8	256.1	333.3	435.9	388.5	487.4
31	43.2	35.8	51.7	256.3	223.9	292.1	409.6	364.4	458.7
32	33.2	26.8	40.7	205.2	176.4	237.3	339.3	298.4	384.2
33	31.2	24.7	38.8	194.3	166.6	225.4	346.6	306.9	390.0
34	41.4	34.5	49.4	260.1	227.8	295.7	404.2	355.7	457.4
Missouri	41.9	40.6	43.2	268.9	263.1	274.8	428.0	419.6	436.5

Table 2. Female Breast Cancer (FBC) Incidence Rates among White and African-American Females in Missouri

Senatorial Districts	<i>White Race</i>			<i>Black Race</i>		
	<i>Rate</i>	<i>LL</i>	<i>UL</i>	<i>Rate</i>	<i>LL</i>	<i>UL</i>
1	141.5	131.6	152.0	176.8	121.7	248.1
2	139.1	128.4	150.6	152.9	86.8	247.0
3	119.7	110.3	129.9	^	^	^

4	139.6	126.9	153.2	135.4	119.0	153.5
5	134.9	116.9	154.9	131.1	116.8	146.5
6	116.6	107.2	126.6	106.3	50.1	193.2
7	129.5	117.8	142.2	131.9	108.5	158.9
8	120.1	110.1	130.9	132.3	81.6	201.1
9	120.0	103.9	138.1	146.1	132.3	160.9
10	121.4	111.7	131.8	142.2	86.3	219.7
11	117.5	107.6	128.1	116.9	79.8	164.6
12	118.0	108.8	127.8	^	^	^
13	133.1	119.0	148.6	139.8	125.0	156.0
14	145.2	128.6	163.5	144.3	130.2	159.5
15	155.6	145.5	166.4	100.8	42.3	201.8
16	117.9	108.3	128.1	66.1	26.3	138.9
17	136.2	125.6	147.6	99.8	52.2	171.0
18	120.6	111.1	130.6	186.0	114.3	284.1
19	132.0	120.6	144.2	175.5	126.6	235.7
20	123.5	114.0	133.7	^	^	^
21	114.6	105.3	124.6	87.9	46.5	151.0
22	115.3	105.5	125.8	^	^	^
23	134.4	124.1	145.4	147.8	90.3	228.5
24	153.8	142.7	165.5	132.0	102.4	167.5
25	108.7	99.6	118.6	101.2	72.7	136.9
26	140.2	130.3	150.7	84.3	32.8	198.6
27	115.2	105.8	125.3	128.4	82.2	190.3
28	111.8	103.1	121.0	^	^	^
29	104.9	96.6	113.8	^	^	^
30	130.4	119.9	141.5	78.4	33.4	152.5
31	121.1	111.6	131.2	117.3	53.4	220.5
32	99.4	90.8	108.6	^	^	^
33	96.1	87.8	104.9	^	^	^
34	120.3	110.6	130.6	105.8	60.4	170.4
Missouri	123.8	122.1	125.6	134.8	129.4	140.5

^: Incidence statistics based on a small number of new cases are suppressed to help protect confidentiality. As commonly used by MCR-ARC and other central cancer registries, a threshold of five (5) was utilized.

Table 3. Incidence Rates of All Malignant, High Grade, and Late Stage Female Breast Cancer (FBC) in Missouri (2008-2012)

Senatorial Districts	<i>All Malignant</i>			<i>High Grade (III + IV)</i>			<i>Late Stage (R+D)</i>		
	<i>Rate</i>	<i>LL</i>	<i>UL</i>	<i>Rate</i>	<i>LL</i>	<i>UL</i>	<i>Rate</i>	<i>LL</i>	<i>UL</i>
1	43.7	39.9	47.8	28.0	25.1	31.2	29.3	26.6	32.1
2	34.7	30.8	39.0	27.8	24.4	31.4	28.9	25.9	32.1
3	50.8	46.4	55.5	37.5	33.6	41.6	33.4	30.0	36.9
4	50.3	45.9	55.0	34.3	31.0	37.8	29.6	26.8	32.6
5	54.1	48.8	59.8	46.9	42.5	51.3	38.6	34.9	42.3
6	42.1	38.3	46.3	29.2	25.6	33.1	24.4	21.4	27.5
7	38.0	34.0	42.4	32.9	29.2	36.8	30.0	26.9	33.3
8	38.0	33.9	42.5	33.2	29.3	37.2	29.1	25.9	32.5
9	51.7	46.9	56.8	38.0	34.1	41.9	36.1	32.7	39.5
10	44.5	40.3	48.9	24.2	20.8	27.7	29.5	26.2	32.8
11	44.4	40.3	48.9	29.1	25.4	32.9	33.8	30.4	37.4
12	45.5	41.6	49.7	33.7	30.0	37.5	31.1	27.9	34.5
13	48.6	44.2	53.3	36.6	33.0	40.2	32.5	29.5	35.6
14	50.6	46.0	55.6	42.4	38.7	46.1	32.2	29.2	35.2
15	46.2	42.3	50.4	29.9	27.0	32.9	26.3	23.9	28.8
16	45.6	41.4	50.0	35.5	31.5	39.5	33.5	30.1	37.1
17	42.7	38.3	47.3	31.2	27.6	34.9	30.0	26.8	33.3
18	52.4	48.2	56.9	29.6	26.1	33.3	31.0	27.9	34.3
19	40.9	36.4	45.7	31.9	28.1	35.9	25.5	22.3	28.8
20	36.4	32.6	40.5	37.4	33.7	41.3	27.4	24.4	30.6
21	46.1	41.9	50.5	32.4	28.6	36.4	34.1	30.7	37.7
22	44.9	40.2	50.1	35.0	30.9	39.2	29.6	26.2	33.2
23	40.5	36.4	44.9	30.5	27.1	34.0	31.2	28.2	34.4
24	40.3	36.7	44.1	30.7	27.7	33.8	26.2	23.7	28.8
25	52.8	48.5	57.4	35.1	31.2	39.2	34.5	31.0	38.2
26	39.7	36.0	43.8	32.0	28.8	35.3	25.5	22.9	28.3
27	43.1	39.2	47.3	36.2	32.3	40.2	30.7	27.3	34.2
28	42.7	39.1	46.7	41.7	37.9	45.6	33.1	29.9	36.4
29	39.8	36.2	43.6	34.8	31.1	38.7	33.9	30.5	37.4
30	42.8	38.7	47.3	37.6	33.9	41.5	27.7	24.7	30.9
31	46.2	42.1	50.6	36.3	32.6	40.2	32.5	29.3	35.9
32	46.1	42.1	50.5	44.7	40.4	49.1	30.5	27.0	34.2
33	45.5	41.5	49.8	38.1	33.9	42.4	26.2	22.9	29.7
34	44.3	40.1	48.9	30.7	27.0	34.5	26.4	23.3	29.7
Missouri	44.5	43.8	45.2	34.0	33.4	34.6	30.2	29.7	30.8

From the current study's results, as shown in tables # 1, 2, and 3, we can build FBC incidence profiles for the 34 Missouri senate districts. These profiles enable us to compare individual district's results to Missouri and the other 33 districts' incidence data.

The current study's investigators produced senatorial district interactive reporting maps using the Census Bureau's Cartographic Boundary Shapefiles. Our senior statistician uploaded these mapping data along with the FBC incidence results obtained by analyzing MCR data using SEER*Stat to InstantAtlas™ to generate interactive maps [16, 17].

These interactive maps, in addition to the FBC incidence rates, also display FBC and other cancers' mortality and survival data by county, senatorial district, and senatorial districts grouped to county boundaries (SDGCs). The maps visualize FBC incidence data and these mapping reports are in two layouts: Area profile and double map formats.

These maps consist of joint spatial and statistical data. The following figures show the final layouts of the InstantAtlas™ mapping reports we constructed at the MCR-ARC to present Missouri FBC incidence data. In each map, District 19 is outlined in red.

Figure 1. Area Profile Interactive InstantAtlas™ Report Displaying Female Breast Cancer (FBC) Incidence Data by Senatorial District [16]

Figure 2. Double Map Interactive InstantAtlas™ Report Displaying Female Breast Cancer (FBC) Incidence Data by Senatorial District [17]

Both mapping reports display our results in different formats (e.g., charts, tables, maps) [16, 17]. The area profile report shows a single map and focuses on displaying many indicators for every senate district and compares a district's findings to other districts and to Missouri. The double map focuses on exploring the inferential statistical relationships between the selected indicators. [16, 17].

We studied the FBC incidence data results for District 19 and we compared the district's results to the Missouri FBC incidence data. The following figures show the findings.

Figure 3. Female Breast Cancer (FBC) Incidence Rates by Age for Senate District 19 and Missouri (2008-2012)

Figure 4. Female Breast Cancer (FBC) Incidence Rates by Race for Senate District 19 and Missouri (2008-2012)

Figure 5. Female Breast Cancer (FBC) Incidence Rates by Stage and Grade Percentages for Senate District 19 and Missouri (2008-2012)

District 19 includes the city of Columbia, which is the fifth largest city in Missouri according to the 2010 US Census and the population center of the Columbia Metropolitan Statistical Area (MSA). In this study, we compared District 19 to the state's FBC incidence data.

As Figures 3, 4, and 5 show, for all races and ages District 19's incidence rates were higher than Missouri's rates. Women >50 years old have a higher incidence rate than women <50 years old in District 19 and the state. For District 19, the incidence rate among women >50 years old was higher than the state's rate for the same age category. The FBC incidence rates for whites and African Americans were higher within District 19 than in Missouri as a whole. From Figure 4, we could see that the FBC incidence within District 19 was higher by about 40/100,000 population among African-American

women than among white women. The FBC incidence rate for African-American women in District 19 was significantly higher than the state rate. However, none of the above-mentioned differences between District 19 and Missouri were statistically significant at $\alpha=.05$.

As we see from Figure 5, FBC incidence rates for late stage and grade percentages of District 19 were lower than Missouri's incidence rate. The difference in stage was statistically significant at $\alpha=.05$, with a higher late-stage FBC incidence rate in Missouri than in District 19.

Figures 6, 7, and 8 show the comparison in FBC incidence rates between District 19, the combined districts 20 & 30, and Missouri.

Figure 6. Female Breast Cancer (FBC) Incidence Rates by Age for Senate District 19, Combined Districts 20 & 30, and Missouri

Figure 7. Female Breast Cancer (FBC) Incidence Rates by Race for Senate District 19 and Combined Districts 20 & 30 (2008-2012)

Figure 8. Female Breast Cancer (FBC) Incidence Rates by Stage and Grade Percentages for Senate District 19 and Combined Districts 20 & 30 (2008-2012)

For all malignant FBC, the incidence rate for District 19 was higher than the combined districts 20 & 30 and Missouri. The incidence rates were comparable among each of the <50 and 50-64 age categories for both areas. However, for the 65+ age category, the FBC incidence rate for District 19 was higher than the combined districts 20 & 30's incidence rate. Among white females, both areas were comparable and there was no significant difference. The FBC incidence rate among African Americans was higher for District 19 than for the combined districts 20 & 30. The percent of late stages and grades at diagnosis was lower in District 19 than combined districts 20 & 30 and Missouri.

However, none of the above-mentioned differences between District 19 and the combined districts 20 & 30 were statistically significant at $\alpha=.05$.

Discussion

Central cancer registry databases are created from a variety of sources, including hospitals, pathology labs, ambulatory surgical centers, skilled nursing facilities, physician offices, and free-standing cancer clinics and treatment centers. The MCR data underwent strict quality control values and measures and the data has been assessed continually according to precise nationwide standards [1, 2].

Calculating and visualizing FBC age-standardized incidence rates by senatorial district could help public health officials and policy makers be informed about FBC distribution by age, race, grade, and stage at diagnosis within a senatorial district. This might effectively impact FBC policy and research, determine female at-risk sub-groups, support targeting FBC geographical foci, and evaluate and compare diagnostic and treatment strategies all over Missouri.

District 19 and Missouri:

Missouri women with an income at or below 200 % of the governmental poverty level who are age 35 to 64 (or older if they do not receive Medicare Part B) and who do not have insurance to cover program services are eligible for free breast cancer screening through Show Me Healthy Women (SMHW), Missouri's implementation of the National Breast and Cervical Cancer Early Detection Program (NBCCEDP)[18]. This could result in elevating FBC incidence rates in Missouri. District 19's population is mostly urban and we hypothesize that most of the district's residents who do not have insurance that covers breast cancer screening could access these free available services. This might explain why FBC incidence rates were higher in District 19 than in the majority of rural Missouri, where eligible women might not easily access or be educated about these free services. Many studies have found that screening for breast cancer seems to discover additional breast cancers that are possibly clinically trivial [19, 20]. Therefore, the high FBC incidence in District 19 might be due to over-diagnosis of early breast cancer cases among highly educated, mostly urban inhabitants who have easy access to screening services. Missouri is about 30% rural, where a higher percent of residents have less education and are more likely to have difficulties in healthcare accessibility and coverage; this could explain why the state FBC incidence rate was lower than District 19's rate [21]. Some studies have revealed cancer screening, diagnostic, and treatment disparities and inequalities between rural and urban areas. The findings were explained as being due to limited accessibility, poverty, and high Medicare copayment [22, 23, 24]. A study published in 2015 determined that cancer disparities might be reduced by

increasing the accessibility of under-privileged at risk and rural residents to governmental community facilities [25].

Among African-American women, the incidence rate was higher for District 19 than the entire state. African-American population percentages are higher in the major metropolitan areas than in the rural areas of the state [26]. Since a study published in 2012 revealed racial cancer disparities among breast cancer cases [27], our study findings could be interpreted as rural African-Americans in Missouri as a whole have lower physical accessibility to screening services and education than urban District 19's African-Americans.

District 19 embraces Columbia, a minor metropolitan area. This city contains the campus of the University of Missouri-Columbia. The campus is inhabited by a highly-educated population who have health coverage and access to most healthcare services, including screening and treatment services. This might partially account for the higher FBC incidence rates for whites, African Americans, and all races in District 19 than in Missouri.

Missouri high stage and grade FBC incidence rates were also higher than District 19's rates. This could be explained that District 19 inhabitants have had higher education and higher rate healthcare coverage and accessibility to get screened for FBC and the opportunity of discovering treatable FBC early stages and grades. This might give them a higher chance to be diagnosed with FBC earlier than most women in rural Missouri.

District 19 and Combined Districts 20 & 30:

The comparison findings of higher late stage and grade at diagnosis percentages in the combined districts 20 & 30 and Missouri than District 19 could be explained by over-diagnosis due to using of the free screening services by District 19's residents [25, 26]. So, FBC cases in the District 19 tended to be diagnosed *in situ* or at an early invasive stage and these cases are successfully treatable and do not proceed to the FBC late stages. Therefore, the incidence pool of late-stages incidence rates was lower in District 19 than in combined districts 20& 30 and Missouri. For both studied regions, FBC incidence rates did not have a consistent pattern of differences by age and race.

The study findings could be very informative for cancer policy makers and public health professionals in both studied regions. Findings might motivate partnership between policy makers and other public health officials to analyze and evaluate screening and management cancer measures and other behavioral and socioeconomic indicators for the benefit of women in these areas and Missouri.

Potential Problems and Alternative Approaches

In high population density areas – Kansas City metropolitan area, Saint Louis metropolitan area and the City of Springfield – district boundaries do not follow county boundaries [28]. In these areas, the Census Bureau's TIGER/Line shapefiles software was used to determine the district containing the latitude and longitude of the address at diagnosis [14].

A problem encountered is that we did not have successfully geocoded street addresses of all FBC cases due to missing or inaccurate addresses. In these situations, we categorized

cases as residents of the most likely senate district by matching to cases that were successfully assigned into their senate district with the same county (if known), race (if known and categorized as white, African-American, or other), year of diagnosis (categorized into two time-periods), and the nine-digit Postal ZIP Code. When multiple senate districts matched, then the most common one was selected; when none matched, then the process was iteratively repeated by removing the least significant digit of the Postal ZIP Code until a senate district was imputed for every case.

Unlike with county-level data, a detailed population file by age (in 19 groups of mostly 5-years except with <1 year-olds and 85+), race (bridged single-race), year, and sex was not found at the senate district level and had to be constructed. The limitations of this population file are that for senate districts that do not follow county boundaries, there is a mismatch between the Office of Management and Budget (OMB) 1977 and 1997 race classifications, granular age-groupings were approximated, and there is an increasing inaccuracy as one moves away from 2009-2013.

Conclusion

Measurement of incidence rates by race, age, and by stage and grade at diagnosis may provide an estimation of social inequality within the state and could provide clues about the impact of level of coverage and accessibility to screening and health care services on disease prevention and early diagnosis [1]. The detailed and visually presented FBC age-adjusted incidence profiles by senate districts might lead researchers and policy makers to understand effectiveness of current breast cancer initiatives and interventions by district and might give clues about possible environmental and socioeconomic risk factors on breast cancer.

According to the study results and by future research based on these results, policy makers might embrace new effective breast cancer screening and prevention initiatives and interventions in Missouri, nationally and internationally.

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Estimated Female Breast Cancer Mortality-to-Incidence Ratio (MIR) of the Counties and the Senatorial Districts Grouped to County Boundaries (SDGCs) in Missouri, 2008 – 2012

Abstract

Objectives: To measure mortality-to-incidence Ratio (MIR) on senatorial districts grouped to county boundaries (SDGCs) to explore female breast cancer (FBC) racial and age disparities in Missouri.

Methods: The MIRs and their 95% confidence interval (CI) by age and race were calculated for 20 SDGCs for the period from 2008-2012.

Results: For the 65+ year old FBC cases, MIRs for Missouri and the 20 SDGCs were typically twice the MIR for the <50 and 50-64 year-old categories. The MIRs for all of Missouri and the compared SDGCs were higher for African-Americans than whites.

Conclusions: FBC MIRs can be used as a measure of cancer inequalities in Missouri. These measures might be informative for policy makers to assess existing policies and enforce effective interventions to tackle FBC disparities.

Key Words: Disparities, female breast cancer, Mortality-to-Incidence Ratio, Race

Introduction

As a statistic, incidence rates estimate the actual underlying incidence of some conditions, but they are influenced by a number of factors. For example, incidence rates will be increased by increasing the intensity of breast cancer screening measures and interventions and these rates might be reduced by increasing prevention measures for cancer risk factors [1]. The incidence rates will be affected by any changes in the coding

and classification of any cancer. The central cancer registry database is considered to be a high quality controlled source to estimate the most accurate epidemiological rates because it is following very strict regularly updated measures and standards [2, 3]. Many studies have concluded the importance of estimation of multiple epidemiological indicators of cancers together, because presenting these epidemiological measures individually may mislead readers; therefore, we will conduct this project to include all the measurements of the same period of time [1, 3]. Many studies revealed that there are inequalities between cancer cases according to age, race, stage and grade at diagnosis variables [4, 5, 6, 7, 8, 9].

Cancer mortality rates could inform public health leaders if the cancer is a public health priority at the level of state senate districts in Missouri. Using the National Vital Statistics System (NVSS) database of the National Center of Health Statistics (NCHS) to clarify cancer mortality is an excellent source of demographic, geographic and cause of death data [10]. Mortality rates could measure possible over-diagnosis bias in the breast cancer incidence and survival rates [1].

Cancer mortality is considered as a disparity indicator, but without measuring the corresponding incidence it could be misleading. Elevated mortality could result from rare lethal cancer survival with very low incidence or from a modest survival cancer with high incidence rates of the same cancer [11, 12].

Mortality-to-incidence Ratio (MIR) is a measurement that could expand our interpretation and understanding of the difference between the two compared epidemiological measures. This metric could expand the understanding of the demographic, environmental, and social factors which might lead to unexpected changes

of mortality rates based on the estimated incidence data [13]. Matching MIR for any cancer by race and age offers an influential method to explore the cancer magnitude and prognosis. The MIR will help in exploring and addressing the hidden differences in cancer consequences by area, age, and race [14]. MIR affords a population-based metric of cancer prognosis [15].

Numerous evidence-based studies have concluded that the use of interactive geographic mapping software allows users to interact in a timely way with data sets and publish high quality, interactive reports. The web-based mapping systems' contribution might be significant because these systems could enable users to visualize the interactive mapping breast cancer reports easily and in a timely way, and the users can share this data with contributors in fields related to breast cancer. Distribution of geospatial health data will help public health leaders and decision makers in designing, developing, and adopting effective and efficient strategies and programs to improve public health outcomes targeting specific geographical areas [16,17,18,19].

For instance, there are racial inequalities in cancer incidence and mortality; these variances are usually consequence of complicated sources. In the US, mortality rates of most cancers are higher among African-American than other racial/ethnic categories [20, 12]. For all cancers, the African-American mortality rate is 25% higher than the white mortality rate [21]. For most cancer types, incidence rates are higher among African Americans than among whites and, for some cancers, African Americans are diagnosed with aggressive cancers at younger ages than the whites [14].

The current study's investigators want to estimate the female breast cancer (FBC) incidence using Missouri Cancer Registry (MCR) database, and assess the FBC mortality

of the same period using other national databases. The current study objectives are to: 1) measure incidence rates in Missouri from 2008 to 2012 according to female breast cancer (FBC) cases' age at diagnosis, race, and the senate district grouped to county boundaries (SDGCs) of diagnosis, visualizing the measured rates in InstantAtlas™ interactive mapping reports; 2) analyze FBC mortality rates in Missouri from 2008 to 2012 according to age, race, and SDGC, visualizing the measured mortality rates through InstantAtlas™ interactive mapping reports; and 3) measure mortality-to-incidence ratio (MIR) of the SDGCs to explore FBC racial and age disparities in Missouri.

Methods

Female Breast Cancer Incidence:

The study design is an observational epidemiological study. The investigators did secondary analysis on all female breast cancer cases in the MCR database from 2008 through 2012. At the study's initiation, 2012 was the most recent year of diagnosis with complete data (>95% cases reported). The starting point of 2008 was chosen arbitrarily, but using a 5-year period is common in research. Population data came from the mid-year estimates from the US Census Bureau's Population Estimates Program, which is single-race bridged by National Center of Health Statistics (NCHS) and then released by the National Cancer Institute (NCI)'s Surveillance Epidemiology and End Results (SEER) program. NCI makes some modifications to the NCHS files but these modifications don't impact Missouri. The calculated incidence rates for every Missouri county was age standardized using US 2000 Standard Population for comparability across regions with differing age structures. We calculated the 95% confidence interval (CI) for these rates using SEER*Stat statistical package [22]. The Census Bureau's Cartographic Boundary

Files (CBFs) were used to create maps showing SDGCs with a shapefile produced with ArcMap from the county-level CBF. A set of twenty [17] regions we termed “senate district grouped to county boundaries” (SDGCs) were created that minimally aggregated the districts to follow county boundaries. The 20 SDGCs include each of the 14 districts that followed county boundaries (Senate districts # 6, 10, 16, 18, 19, 21, 25, 27, 28, 29, 31, 32, 33 & 34) along with six aggregated regions: 8 senate districts of Franklin County, St. Louis City, and St. Louis County; 2 senate districts of St. Charles County; 2 senate districts covering 6 counties south of St. Louis; 4 senate districts of Jackson County; 2 senate districts covering 15 counties in northwest Missouri; and 2 senate districts covering Christian and Greene counties. Table 1 shows the SDGCs and their included counties.

Incidence results were loaded along with the Cartographic Boundary Files into InstantAtlas™ software to produce interactive mapping reports that display our study’s results. The maps were published and we will attach them to the MCR-ARC website. The interactive reports include maps, graphs, and tables for the 20 SDGCs [23, 24].

Table 1. Senate Districts Grouped to County Boundaries (SDGCs) and their Involved Counties.

<i>SDGC No.</i>	<i>The Senate District (SD) or Counties (Cs) Involved per SDGC</i>
SDGC #1	SD #6
SDGC #2	SD #10
SDGC #3	SD #16
SDGC #4	SD #18
SDGC #5	SD #19
SDGC #6	SD #21
SDGC #7	SD #25
SDGC #8	SD #27

SDGC #9	SD #28
SDGC #10	SD #29
SDGC #11	SD #31
SDGC #12	SD #32
SDGC #13	SD #33
SDGC #14	SD #34
SDGC #15	901: 01,04,05,13,14,15,24,26 (Franklin, STL City, STL County)
SDGC #16	902: 02,23 (St. Charles)
SDGC #17	903: 03,22 (6 counties south of STL)
SDGC #18	907: 07,08,09,11 (Jackson)
SDGC #19	912: 12,17 (15 Counties in the northwest)
SDGC #20	920: 20,30 (Christian & Greene counties)

Female Breast Cancer Mortality:

The study design is an observational epidemiological study. The investigators used the NCHS death file to capture deaths of former Missouri residents for the period from 2008 to 2012 [22]. The female breast cancer death data was on the county level and SDGC-level only since the investigators could not further geocode this data. We calculated the 95% confidence interval (CI) for these rates as well as testing for differences from the remainder of the state, which are shown in the area health profile report.

As we did for incidence rates, we used the Census Bureau's Cartographic Boundary Files to create maps showing state SDGCs with a shapefile produced with ArcMap from the county-level CBF. The mortality results were loaded along with the CBFs into InstantAtlas™ software to produce interactive mapping reports that display our study's results [25]. We will attach our interactive mapping reports to the MCR-ARC website. The interactive reports included maps, graphs, and tables for the 20 SDGCs and 115 counties [23, 24].

Mortality-to-Incidence Ratio (MIR):

The MIRs by age and race for the FBC cases were calculated by dividing the FBC mortality rates by the age-adjusted FBC incidence rates for the 20 SDGCs for the period from 2008-2012. The researchers also calculated the 95% Confidence Intervals (95% CI) of the calculated MIR ratios on the log-scale using the delta method and then transformed the results back to the original scale. We calculated approximate CI based on a normal approximation to the log of the ratios.

Results

Our map designer at the MCR-ARC built SDGCs maps using InstantAtlas™. These maps were uploaded along with the results we got by analyzing incidence and mortality data using SEER*Stat to the InstantAtlas™ software to create the final interactive mapping reports [23-24]. These reports visualize incidence and mortality data results. The results were displayed in two formats: area profile and double map. These reports include combined maps and statistical data. The following screen shots show the final formats of the InstantAtlas™ mapping reports we built to display our results.

Figure 1. Area Profile Mapping Report of 65+ Female Breast Cancer (FBC) Incidence Rates by Senate Districts Grouped to County Boundaries (SDGCs) in Missouri 2008-2012 [23]

Figure 2. Area Profile Mapping Report of Female Breast Cancer (FBC) Mortality Rates of Whites by Senate Districts Grouped to County Boundaries (SDGCS) in Missouri 2008-2012 [23]

Figure 3. Double Map InstantAtlas™ Report of 65+ Female Breast Cancer (FBC) Incidence and Mortality Rates by Senate Districts Grouped to County Boundaries (SDGCS) in Missouri 2008-2012 [24]

From all the above maps, we could create individual FBC mortality and incidence profiles for the constructed 20 SDGCs. By creating these profiles, we could compare the SDGCs' results to the state and compare the SDGCs to each other. This might give evidence to public health professionals and cancer policy makers about FBC in their areas, how to evaluate cancer laws and policies, and how to consider the possible risk factors per area to positively impact cancer research and policy.

Table 2. Female Breast Cancer (FBC) Mortality-to-Incidence Ratio (MIR) and the MIR 95% Confidence Intervals (95% CI) by Senate Districts Grouped to County Boundaries (SDGCS) and by Age in Missouri 2008-2012

SDGC	<50			50-64			65+		
	MIR	95% CI LL	95% CI UL	MIR	95% CI LL	95% CI UL	MIR	95% CI LL	95% CI UL
Missouri	0.12	0.11	0.13	0.17	0.12	0.15	0.26	0.16	0.24
SDGC #1	0.17	0.10	0.27	0.24	0.17	0.12	0.31	0.17	0.19
SDGC #2	0.10	0.05	0.18	0.21	0.10	0.10	0.26	0.14	0.15
SDGC #3	0.14	0.08	0.25	0.25	0.14	0.12	0.35	0.18	0.21
SDGC #4	0.17	0.10	0.28	0.22	0.17	0.11	0.32	0.15	0.20
SDGC #5				0.19		0.09	0.25	0.13	0.14
SDGC #6	0.22	0.14	0.35	0.26	0.22	0.13	0.35	0.18	0.21
SDGC #7	0.12	0.07	0.22	0.33	0.12	0.18	0.37	0.24	0.23
SDGC #8	0.11	0.06	0.20	0.28	0.11	0.14	0.37	0.20	0.22
SDGC #9	0.16	0.09	0.28	0.27	0.16	0.15	0.33	0.20	0.21
SDGC #10				0.21		0.09	0.29	0.14	0.18
SDGC #11	0.14	0.08	0.23	0.20	0.14	0.09	0.38	0.14	0.24
SDGC #12	0.16	0.09	0.27	0.27	0.16	0.13	0.37	0.19	0.22
SDGC #13				0.30		0.15	0.41	0.21	0.25
SDGC #14	0.09	0.05	0.16	0.20	0.09	0.10	0.31	0.14	0.18
SDGC #15	0.10	0.08	0.12	0.17	0.10	0.14	0.24	0.15	0.20
SDGC #16	0.10	0.07	0.15	0.16	0.10	0.10	0.27	0.13	0.18
SDGC #17	0.12	0.08	0.18	0.19	0.12	0.11	0.36	0.14	0.25
SDGC #18	0.16	0.13	0.21	0.23	0.16	0.16	0.28	0.19	0.21
SDGC #19	0.08	0.05	0.12	0.19	0.08	0.11	0.32	0.15	0.22
SDGC #20	0.12	0.08	0.18	0.19	0.12	0.11	0.27	0.15	0.19

^: Mortality and incidence statistics based on small number of deaths and new cases are

suppressed to help protect confidentiality. In accordance with NCHS's policies, the threshold of ten deceased was utilized and, as commonly used by MCR-ARC and other central cancer registries, the threshold of five was utilized for new cases.

followed county boundaries (senate districts # 6, 10, 16, 18, 19, 21, 25, 27, 28, 29, 31, 32, 33 & 34), along with the following six aggregated regions: 8 senate districts of Franklin

County, St. Louis City, and St. Louis County; 2 senate districts of St. Charles County; 2 senate districts covering 6 counties south of St. Louis; 4 senate districts of Jackson County; 2 senate districts covering 15 counties in northwest Missouri; and 2 senate districts covering Christian and Greene counties.

Table 3. Female Breast Cancer (FBC) Mortality-to-Incidence Ratio (MIR) by Senate Districts Grouped to County Boundaries (SDGCS) and by Race in Missouri 2008-2012

SDGC	White			African American		
	MIR	95% CI LL	95% CI UL	MIR	95% CI LL	95% CI UL
Missouri	0.18	0.17	0.19	0.25	0.23	0.27
SDGC #1	0.19	0.16	0.24	^	^	^
SDGC #2	0.16	0.13	0.20	^	^	^
SDGC #3	0.21	0.17	0.25	^	^	^
SDGC #4	0.19	0.16	0.23	^	^	^
SDGC #5	0.14	0.11	0.18	^	^	^
SDGC #6	0.22	0.18	0.27	^	^	^
SDGC #7	0.22	0.18	0.27	0.35	0.19	0.65
SDGC #8	0.20	0.17	0.25	^	^	^
SDGC #9	0.22	0.18	0.26	^	^	^
SDGC #10	0.17	0.14	0.21	^	^	^
SDGC #11	0.21	0.17	0.25	^	^	^
SDGC #12	0.23	0.19	0.28	^	^	^
SDGC #13	0.24	0.20	0.29	^	^	^
SDGC #14	0.17	0.13	0.20	^	^	^
SDGC #15	0.15	0.14	0.16	0.24	0.21	0.27
SDGC #16	0.16	0.14	0.19	^	^	^
SDGC #17	0.20	0.18	0.24	^	^	^
SDGC #18	0.19	0.17	0.21	0.26	0.21	0.31
SDGC #19	0.18	0.16	0.21	^	^	^
SDGC #20	0.17	0.15	0.20	^	^	^

^: Mortality and incidence statistics were based on small number of deaths and new cases are suppressed to help protect confidentiality. In accordance with NCHS's policies, the threshold of ten deceased was utilized and, as commonly used by MCR-ARC and other central cancer registries, the threshold of five was utilized.

From the MIR interactive area profile and double maps and from tables 2 and 3, we detected large differences in MIR by age and race for FBC in Missouri and across the SDGCs. These MIR differences were significant. For the 65+ FBC cases, the MIR for whole Missouri and the 20 SDGCs were mostly twice the MIR for the <50 and 50-64 years old categories. In Missouri, the 65+ years old population has increased more than other age categories. It represents 13 % of the total population and it is expected that by 2030 will be more than 21% because of the baby boomers [27]. Females of 65+ years old represented 50.9% of the total population in 2015 [28]. This group is mostly eligible for Medicare services.

According to the 2010 U.S. Census, the total African-American population count was 693,391, representing about 11.6% of the entire Missouri population [29]. African-American population percentages are higher in the major metropolitan areas than in rural areas of the state [29]. In 2015, according to the U.S. Census Bureau, Missouri's white population represented 83.3% and the African-American population represented 11.8% of the state's total population [28]. The current study results support findings of a very large study done in Georgia and published in 2012 where African-Americans had higher MIRs than whites for each cancer type [30].

From the interactive map and tables 2 and 3, the current study revealed large spatial inequalities by age and race; these inequalities were based on rural and urban geographical distribution. For FBC cases <50 years of age, the purely rural SDGC #6 had the highest MIRs, followed by three other rural SDGCs -- 4, 9, and 12. The urban SDGC #18, which is a metropolitan area including Kansas City, also had a high MIR. FBC cases in the 50-64 age group had similar MIR findings to the FBC cases in the <50 group. For the 65+ FBC population, the highest MIRs were distributed over most of the rural SDGCs but did not include SDGCs that included metropolitan areas.

Discussion

There are no previous efforts at MCR-ARC to assess MIR ratio variances among FBC cases by age and race in Missouri. By measuring these ratios, we could extend our understanding of the potential destiny of the diagnosed cancer cases.

The significantly high MIRs among the 65+ years old FBC cases, in comparison to the other two age categories, might be interpreted as the comorbidity in 65+ year-old cases restricting the capability to get good prognostic choices, for example, axillary lymph node dissection. Comorbidities might limit management decisions, such as exposure to strong chemotherapy courses with or without radiotherapy. Additionally, the death from causes other than breast cancer of the FBC cases might be missed by the death certificate writers to be attributed to the breast cancer [31]. As a retrospective cohort study was conducted on FBC of different age categories, ≥ 70 year-old FBC cases were significantly less likely to get management plans consistent with their breast cancer at diagnosis stages and grades than younger FBC cases [31]. The same study revealed that diabetes, renal failure, stroke, liver disease, a previous malignant tumor, and smoking

were significant in expecting premature death for this FBC category [31]. Despite Medicare coverage of the 65+ year-old females across Missouri, the highest MIRs for the 65+ year-old FBC cases were for rural Missouri. This could be attributed to the lack of accessibility of rural FBC cases to oncology services, lack of treatment follow-up and compliance, poverty, and/or to the cost of Medicare copayment [32,33].

A study published in 2007 found that insurance status and coverage has an important impact on treatment options and health consequences. Uninsured patients often have less intensive management and they tend to be discharged rather than referred for continuous care. The study revealed that uninsured patients or those with limited insurance coverage are more likely to be discharged from the hospital in an unhealthy condition [33]. The researchers explained these findings with a shortage in federal law in requiring providers to ensure that their patients receive all necessary care or that they be transferred to the most appropriate treatment setting [33].

Huge spatial rural-urban inequalities for the <65 year-old FBC cases were discovered by the current study; higher MIRs were found for rural SDGCs than the urban and metropolitan SDGCs. These findings could be attributed to poverty, lack of coverage, and inaccessibility to available diagnostic and treatment due to limited eligibility to Medicaid services for the poor and rural at-risk population. Despite Medicare coverage of the 65+ year-old females across Missouri, the highest MIRs for the 65+ year-old FBC cases were for the rural Missouri. This could be attributed to the lack of accessibility of the rural FBC cases to the right oncology services, lack of treatment follow-up and compliance, poverty, and/or due to the cost of Medicare copayment [32, 33]. The current study also revealed that the SDGCs which have better healthcare services, higher education, and

good socio-economic situation had lower MIRs, especially among white FBC cases [32, 33]. Another study published in 2015 concluded that high cancer MIRs could be decreased by increasing the accessibility of disadvantaged minorities and rural inhabitants to federally-supported community centers [34]. Also, a study published in 2006 concluded that cancer patient navigation assistance by providers could reduce MIRs and cancer disparities [35].

Conclusion

MIRs afford a distinctive measure of cancer inequalities. MIRs could be used to estimate the fatality of FBC and to explore FBC age and racial disparities by area. This might help policy makers and intervention designers to tackle FBC effectively and efficiently in Missouri. From all of this, MIR ratios could construct a significant opportunity in outlining and resolving cancer disparities in Missouri.

There is a plan to map the MIRs by SDGC in the near future. The mapped MIR ratios could be used to locate areas in need of suitable, intensive, extra consideration.

According to the current study and previous studies' results, there is a great need to conduct further evidence-based research exploring cancer comorbid diseases, social, behavioral, and environmental risk factors which might lead to health disparities among diagnosed cancer cases.

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Estimate Female Breast Cancer Survival Data in Missouri Senatorial Districts and Improve Visualization of the Obtained Results Using Interactive Mapping Reports, 2004 – 2010

Abstract

Background: The Missouri Cancer Registry (MCR) collects population-based cancer incidence data on Missouri residents diagnosed with reportable malignant neoplasms (192.650-192.657 RSMo). MCR wanted to produce data that would be of interest to law-makers and public health officials at the legislative district-level on breast cancer, the most common non-skin cancer among females. Our initial focus is on Missouri Senate District 19 (Boone and Cooper counties) and districts 20 & 30 combined (Greene and Christian counties). Missouri Senate District 19 contains the city of Columbia and Districts 20 & 30 contain the city of Springfield. These are the two largest cities in Missouri outside the St. Louis and Kansas City metropolitan areas.

Objectives: Measure and interactively visualize survival data of female breast cancer (FBC) cases in the Missouri Cancer Registry (MCR). Secondly, assess the geocoder we used to determine FBC cases' senatorial districts.

Methods: FBC data were linked to Missouri death records and Social Security Death Index (SSDI). Unlinked FBC cases were cross-matched to the National Death Index (NDI). FBC cases in sub-county senate districts were geocoded using TIGER/Line Shapefiles to identify their districts. A database was created and analyzed in SEER*Stat. Senatorial district maps were created using U.S. Census Bureau's Cartographic Boundary Files. The results were loaded with the cartographic data into InstantAtlas™ software to

produce the interactive mapping reports. SAS and ArcMap were used to study the relationship between the types of address vs the certainty that our geocoder gave corresponding to addresses' Census Tracts.

Results: All 34 senatorial districts FBC survival profiles of 5-year cause-specific survival percentages and 95% CI in the form of tables and interactive maps were created. The comparisons of District 19's survival to Missouri and to the combined districts 20 & 30 were conducted. The maps visualized survival data by age, race, stage, grade at diagnosis, and by senatorial district from 2004 to 2010. There was substantial urban–rural difference in the accuracy of geocoded data.

Conclusion: Linking cancer registries' data could improve accuracy of FBC survival, and could impact cancer research and policy.

Key Words: Survival, Female Breast Cancer, Missouri, Cancer Registry.

Introduction

In the United States (US), it is estimated that 12 percent of women will be diagnosed with breast cancer at one stage of their lives [1]. Nationally, the estimated new cases of breast cancer were 14 percent of all new cancer cases and the estimated deaths from breast cancer were 7 percent of all cancer deaths in 2013 [2].

Traditionally, incidence and mortality rates have been presented in data tables, a format that is easily understood by epidemiologists and statisticians but one that does not meet the needs of all potential users of the data. Data visualization is an alternative means of portraying the burden of breast cancer at various levels (e.g., county, region, state, etc.).

There is a critical need to build accurate fact sheets in the form of interactive and dynamic map reports of the breast cancer burden at the sub-state level in Missouri. Several studies emphasize the efficiency and importance of matching National Death Index (NDI) data to cancer registry data to ensure high quality and accurate population-based cancer survival rates [3, 4, 5]. We matched the registry breast cancer data to the Social Security Death Index (SSDI) and the NDI. This contribution will be significant because, with more complete data to analyze, we can accurately estimate survival rates for the State of Missouri.

Numerous evidence-based studies have concluded that the use of geographic mapping software allows users to interact in a timely manner with the data sets and publish high quality, interactive reports [6, 7, 8]. The web-based mapping systems' contribution is significant because these systems will enable users to visualize cancer data easily, and users can share this data with contributors in fields related to the visualized cancer. Distribution of geospatial health data could help public health leaders and decision makers in designing, developing and adopting effective and efficient strategies and programs to improve public health outcomes targeting specific sub-populations within geographical areas [6,7, 8].

A study by Koenig, Samarasundera & Chang (2011) recognized the impact of the interactive mapping visualization of health data on the public health field and healthcare related laws and decisions. The study spotted the need for more interaction between map makers and the mapping reports' beneficiaries [9].

The Missouri General Assembly includes 34 senators, each representing one of Missouri's 34 districts. Every senate district includes an annual average population of about 90,000 female residents (176,000 total residents) for the study period (2004-2010). Most of the districts include whole counties. In high population-density areas in the Kansas City metropolitan area, Saint Louis metropolitan area, and the city of Springfield, district limits do not follow county boundaries [10, 11].

We aim to measure the survival rates of female breast cancer (FBC) cases in the Missouri Cancer Registry (MCR) database and to further analyze these survival data by stage and grade at diagnosis, by race, by age and by senatorial district in Missouri from 2004 to 2010. We also aim to visualize the survival data by Missouri state senatorial district by creating interactive mapping reports.

We aim also to compare geographical differences and possible inequalities in survival rates between the districts and the whole state and between similar districts. For this paper, we will focus in detail on the results of the survival data comparison between District 19 and the whole state. We will also compare the survival data for District 19 (Boone and Cooper counties), which includes the city of Columbia, to combined districts 20 & 30 (Greene and Christian Counties), which together embrace the city of Springfield.

To get a sense of the accuracy of the geocoded senatorial districts, we aim to conduct a quick and practical assessment of the geo-certainty of the geocoder the Missouri Department of Health and Senior Services (DHSS) used to geocode FBC cases, in order to determine FBC cases' actual senatorial district for the FBC cases of senatorial districts which do not follow county borders.

Methods

The study design was an observational longitudinal epidemiological study. The Missouri Cancer Registry and Research Center (MRC-ARC) updated its breast cancer data using Missouri DHSS's death records and SSDI. We extracted FBC cases without a known date and cause of death and submitted a formatted file containing required fields to the National Center for Health Statistics for NDI linkage [12]. NDI staff returned a password-protected CD containing the search results along with our original CD. We assessed the results to identify true matches. Partially matched records were reviewed manually using specific criteria (e.g., possible typos, use of spouse's social security number, change of surname, use of compound names in a different order, use of nicknames, etc.). We then updated the FBC database with the linkage results.

Only FBC cases with complete (passive) follow-up through the study cut-off of 31 December 2011 were included in the survival analysis. Cancer registrars at reporting facilities record the county of residence at diagnosis before submitting the case to MCR; MCR staff use standard edits to validate the submission. To obtain sub-county information, MCR data is geocoded by DHSS to obtain the latitude and longitude (among other information) based on the patient's address at diagnosis. FBC cases in counties split by senate districts were loaded into ESRI's ArcMap [13] with the Census Bureau's TIGER/Line Shapefiles [14] to determine their district based on their latitude and longitude. For this project, we used the State Senate Districts that were defined in redistricting following Census 2010 [15].

A database was created in SEER*Stat, a statistical software package for analyzing cancer data [16]. The 5-year cause-specific survival rates and their 95% confidence intervals

(Cis) were calculated for FBC cases diagnosed from 2004 through 2010. Survival was measured in terms of the cause-specific survival using the Surveillance, Epidemiology, and End Results Program (SEER) Cause-specific Death Classification Recode as the end-point [17]. The 5-year FBC survival rates were calculated by age, race, stage and grade for each senate district. To protect patient confidentiality, we suppressed cells with small numbers, employing a commonly-used threshold of five or fewer cases [18].

The U.S. Census Bureau's Cartographic Boundary Files were used to create maps showing Missouri counties and State senatorial districts [19]. Five-year survival statistics were loaded along with cancer incidence and mortality data and the Cartographic Boundary Files into InstantAtlas™ software to produce interactive mapping reports that display our study's results [20]. The interactive reports included maps, graphs, and tables for the 34 Missouri senatorial districts along with 20 regions formed by aggregating senate districts by county boundaries, and with the 115 Missouri counties (including the City of St. Louis—a county-equivalent entity). The aggregated senate district regions, termed senate districts grouped to county boundaries (SDGSs), were formed since mortality data was not available at the sub-county level.

When we geocoded the FBC cases in the sub-county districts, we encountered a problem in that we did not have successfully geocoded street addresses of all the breast cancer cases due to missing or incorrect addresses. To overcome this, we categorized them as residents of the most likely senate district by matching to cases that were successfully assigned into a senate district with the same county (if known), race (if known and categorized as white, African-American, and other), year of diagnosis (categorized into two time-periods), and the nine-digit Postal ZIP Code. If multiple senate districts match,

then the most common one was selected; if none matched, then the process was iteratively repeated by removing the least significant digit of the Postal ZIP Code until a senate district could be imputed for every case.

The years of FBC diagnoses we chose for the current study were from 01/01/2004 through 12/31/2010. This date range is the same as used by the SEER Cancer Statistics Review (CSR) at the time that they had complete data through 2011. Their survival cut-off year was the one before the most recent year of diagnosis with complete data, and they used 7-year periods for calculating 5-year survival. We used the same case selection as SEER, primarily for comparison purposes with the results from other national and international sources.

Early stage FBC cases consist of *in situ* and localized cases; late stage FBC cases include regional and distant cases. Low grade FBC cases involve grades I and II cases; high grade FBC cases include grades III and IV cases.

District 19 and Missouri

District 19 is near the center of the state and consists of Boone and Cooper counties. Boone County contains the city of Columbia, which is Missouri's 5th largest city as of the 2010 Census and is the principle city of the Columbia Metropolitan Statistical Area (MSA). The survival within this district was compared to the entire state. For this comparison, we used a type I error rate (α) of 0.05 for the hypothesis tests.

District 19 and Combined Districts 20 & 30

In this paper, we also compared the survival in District 19 to combined senate districts 20 & 30, which contains a similar metropolitan area, the Springfield MSA. Springfield is

Missouri's 3rd largest city as of the 2010 Census and is also the principal city of the Springfield MSA (the 4th and 6th largest cities in Missouri are satellite cities contained in the Kansas City MSA). The Springfield MSA is comparable and similar in demographic and socioeconomic backgrounds to the Columbia MSA. Compared to Columbia's demographics, Springfield is larger while Columbia is more racially diverse; their Hispanic compositions are similar to each other and to the state (less than 4%). Districts 20 & 30 were grouped together so that the combined region follows county boundaries for analyzing mortality data. This grouping is also useful when comparing against District 19, since District 19 contains non-urban residents in Boone and Cooper counties and not just residents of the city of Columbia. We used a type I error rate (α) of 0.05 for the hypothesis tests in this comparison between the studied areas.

We tested if the regions' differences were statistically significant by determining the overlap of the 95% CIs of the FBC survival data.

Measuring the Certainty of the FBC Cases' Address at Diagnosis Geocoding Process

To assess the accuracy of the geographical data used in this project, we compared the type of geocoder gave in assigning the case's census tract. It shows how the precision is impacted by having cases with a large proportion of addresses that are not in the city style (where the city style is addresses such as "123 E Main St"). Tract certainty was used since "GIS Coordinate Quality" (NAACCR Item #366) is mostly blank in the MCR database. The study researchers used SAS software to assess the Geo-Certainty of the geocoded FBC cases and we visualized the results using ArcMap software [13].

Results

The senatorial districts' 5-year cause-specific survival rates of FBC were categorized, as shown in tables 1-4, according to the following groupings: All malignant FBC cases, FBC cases < 50 years of age, FBC cases 50-64 years, FBC cases ≥ 65 years, white race FBC cases, African-American race FBC cases, in situ and local FBC cases, regional and distant FBC cases, low grade FBC cases, and high grade FBC cases. These tables include the survival data for all the senatorial districts and Missouri, and the 95% confidence intervals of the measured survival data for all the above-mentioned categories. Using these tables, the reader can compare every district to each other as well as to the state's rate.

Table 1. 5-Year Cause-specific Survival Data of Female Breast Cancer across Different Age Groups of Females in Missouri

Senatorial District (SD)	<50 Years Old			50-64 Years Old			65+ Years Old		
	<i>Rate</i>	<i>LL</i>	<i>UL</i>	<i>Rate</i>	<i>LL</i>	<i>UL</i>	<i>Rate</i>	<i>LL</i>	<i>UL</i>
1	91.6	85.5	95.3	90.7	85.6	94.0	85.8	81.3	89.3
2	92.9	87.2	96.1	89.9	84.2	93.6	79.2	71.7	84.9
3	77.2	67.6	84.3	88.8	83.7	92.4	84.0	77.4	88.8
4	89.5	82.2	93.9	86.9	81.7	90.7	76.3	70.9	80.8
5	81.8	74.2	87.4	86.3	79.6	91.0	76.0	68.6	81.8
6	85.6	77.9	90.7	86.6	80.7	90.8	81.0	75.1	85.7
7	86.0	77.6	91.4	86.9	81.0	91.1	83.8	78.0	88.1
8	87.2	80.4	91.7	86.5	80.3	90.8	86.7	80.2	91.2
9	69.0	59.6	76.7	81.8	75.4	86.7	72.0	65.2	77.7
10	90.5	82.8	94.8	86.2	79.9	90.6	83.8	77.9	88.2
11	84.7	75.6	90.6	84.4	78.2	88.9	82.6	77.0	87.0
12	91.1	84.1	95.1	84.7	78.6	89.2	80.8	74.6	85.6
13	85.3	78.3	90.2	84.0	78.3	88.2	79.6	73.9	84.2
14	80.6	73.4	86.0	87.0	81.8	90.8	83.1	76.9	87.7
15	92.5	87.5	95.5	90.6	86.4	93.6	85.1	80.2	88.9
16	87.5	80.0	92.3	84.3	78.1	88.9	82.6	76.9	87.1
17	85.6	77.5	91.0	92.3	87.9	95.2	83.6	77.0	88.4

18	85.4	77.1	90.8	83.4	77.1	88.1	78.1	72.7	82.6
19	87.1	79.9	91.8	87.2	81.0	91.5	83.4	75.5	89.0
20	90.6	83.8	94.6	86.4	80.0	90.8	82.4	75.7	87.4
21	82.7	73.1	89.1	84.9	78.9	89.3	80.0	73.6	85.1
22	87.0	78.3	92.4	90.7	84.8	94.5	80.9	73.0	86.7
23	90.2	83.5	94.3	91.2	86.9	94.2	88.7	83.3	92.4
24	91.0	84.8	94.8	91.0	86.9	93.9	85.2	80.6	88.8
25	82.9	74.3	88.9	81.7	75.7	86.4	79.1	73.2	83.8
26	88.4	81.9	92.6	89.5	84.1	93.2	79.4	73.8	83.9
27	86.6	77.9	92.1	84.8	78.9	89.2	79.7	73.5	84.5
28	84.5	76.2	90.1	85.5	79.5	89.8	82.4	77.2	86.6
29	85.0	75.2	91.2	90.7	85.6	94.0	81.1	75.3	85.6
30	82.0	73.2	88.1	85.8	78.8	90.6	81.6	76.0	86.0
31	87.3	78.6	92.6	87.6	81.5	91.8	78.6	72.0	83.8
32	77.2	67.8	84.1	86.7	80.7	91.0	81.7	75.8	86.4
33	88.2	80.2	93.1	83.8	77.4	88.6	78.6	71.9	83.8
34	87.5	80.1	92.3	85.3	78.7	90.0	80.7	74.4	85.6
Missouri	86.1	85	87.2	87	86.1	87.8	81.4	80.4	82.3

Table 2. 5-Year Cause-specific Survival Data of Female Breast Cancer among White and African-American Females in Missouri

Senatorial District (SD)	White			African-American		
	<i>Rate</i>	<i>LL</i>	<i>UL</i>	<i>Rate</i>	<i>LL</i>	<i>UL</i>
1	88.8	86.0	91.1	88.4	68.2	96.1
2	87.1	83.6	89.9	88.9	43.3	98.4
3	84.7	81.1	87.8	^	^	^
4	85.4	81.5	88.5	76.4	70.2	81.5
5	85.8	80.2	90.0	78.6	73.0	83.1
6	84.6	81.1	87.4	58.3	23.0	82.1
7	87.6	84.0	90.5	77.7	67.1	85.3
8	86.9	83.3	89.8	77.1	53.2	89.8
9	81.6	75.7	86.2	70.4	64.6	75.5
10	86.1	82.5	89.0	91.8	71.1	97.9
11	83.5	79.9	86.6	84.7	58.4	95.0
12	84.5	80.9	87.4	^	^	^
13	85.4	81.3	88.7	77.6	71.7	82.5
14	89.1	84.6	92.4	79.6	74.6	83.7
15	89.3	86.7	91.4	68.4	35.9	86.8

16	84.7	81.2	87.6	67.3	27.7	88.5
17	87.8	84.5	90.5	75.7	41.6	91.6
18	81.8	78.3	84.8	67.5	41.8	83.8
19	85.1	81.1	88.4	92.1	77.5	97.4
20	85.8	82.2	88.8	^	^	^
21	82.7	78.8	85.9	65.6	34.3	84.7
22	86.0	82.0	89.2	^	^	^
23	90.0	87.1	92.3	85.2	60.6	95.0
24	89.0	86.2	91.2	80.8	67.4	89.2
25	81.6	77.9	84.7	67.4	48.1	80.8
26	85.5	82.3	88.1	100	^	^
27	83.7	80.1	86.7	49.6	14.6	77.4
28	83.9	80.5	86.7	^	^	^
29	85.3	81.8	88.1	^	^	^
30	83.3	79.6	86.3	56.4	7.5	88.1
31	84.1	80.3	87.2	69.1	29.4	89.4
32	82.2	78.4	85.4	^	^	^
33	82.4	78.6	85.6	^	^	^
34	84.5	80.8	87.5	72.8	41.2	89.2
Missouri	85.4	84.8	85.9	76.8	74.7	78.7

^: Survival statistics were based on a small number of FBC survived cases; survival data are suppressed to help protect confidentiality. As commonly used by MCR-ARC and other central cancer registries, the threshold of five (5) cases was utilized.

Table 3. 5-Year Cause-specific Survival Data of All Malignant (Excluding *In Situ* but Including Un-staged FBC Cases), *In Situ* and Local, and Regional and Distant Categories of Female Breast Cancer in Missouri

Senatorial District (SD)	All Malignant			In Situ & Local			Regional & Distant		
	<i>Rate</i>	<i>LL</i>	<i>UL</i>	<i>Rate</i>	<i>LL</i>	<i>UL</i>	<i>Rate</i>	<i>LL</i>	<i>UL</i>
1	88.6	85.9	90.9	96.8	94.7	98.1	77.5	71.3	82.6
2	87.3	83.9	90.1	97.5	95.4	98.6	75.5	68.5	81.2
3	84.4	80.7	87.4	96.1	93.2	97.8	72.3	65.3	78.2
4	82.5	79.2	85.2	95.4	93.0	97.0	68.6	62.5	73.9
5	81.5	77.6	84.8	95.1	92.0	97.0	66.3	58.9	72.6
6	84.0	80.5	86.9	94.7	92.2	96.4	70.7	63.5	76.7

7	85.4	81.9	88.3	95.9	93.3	97.5	74.4	67.8	79.8
8	86.7	83.2	89.5	95.5	92.8	97.2	78.0	71.0	83.5
9	75.0	70.9	78.6	92.1	88.7	94.5	60.4	53.5	66.6
10	86.2	82.7	89.0	95.7	93.1	97.3	76.4	68.9	82.2
11	83.6	80.1	86.6	94.6	91.8	96.4	74.1	67.5	79.6
12	84.5	80.9	87.4	95.3	92.6	97.0	71.7	64.5	77.8
13	82.6	79.3	85.4	94.6	92.1	96.3	69.8	63.7	75.1
14	83.9	80.6	86.7	96.2	93.7	97.7	71.7	65.8	76.8
15	89.0	86.4	91.1	96.3	94.3	97.6	78.3	72.6	82.9
16	84.3	80.8	87.2	95.2	92.5	96.9	74.5	67.7	80.2
17	87.4	84.1	90.1	97.7	95.5	98.9	73.4	66.1	79.3
18	81.3	77.8	84.3	94.9	92.2	96.7	67.7	61.1	73.4
19	86.0	82.3	89.0	95.7	92.6	97.5	73.0	65.5	79.0
20	85.9	82.3	88.8	95.6	93.0	97.3	77.1	70.0	82.7
21	82.3	78.5	85.5	95.8	92.8	97.6	68.7	61.7	74.7
22	86.4	82.5	89.5	95.4	92.4	97.2	76.2	68.1	82.6
23	90.0	87.2	92.2	97.8	95.6	98.9	80.4	74.5	85.1
24	88.5	85.9	90.7	96.5	94.5	97.8	77.2	71.3	81.9
25	80.8	77.2	83.9	94.7	92.0	96.6	66.4	59.4	72.5
26	85.4	82.3	88.1	94.9	92.4	96.6	74.1	67.6	79.5
27	83.0	79.4	86.0	94.6	91.7	96.5	69.6	62.3	75.7
28	84.0	80.6	86.8	95.7	93.1	97.4	73.3	67	78.6
29	85.2	81.8	88.0	96.7	94.4	98.1	71.5	63.8	77.9
30	83.0	79.4	86.1	94.2	91.2	96.2	69.5	62.1	75.7
31	83.8	80.1	86.9	94.4	91.4	96.4	75.0	67.6	80.9
32	82.4	78.7	85.6	94.7	91.8	96.5	67.2	59.5	73.8
33	82.6	78.7	85.7	93.0	89.6	95.3	69.7	62.0	76.2
34	84.1	80.5	87.1	96.0	93.4	97.6	70.8	63.3	76.9
Missouri	84.5	84.0	85.0	95.5	95.1	95.8	72.3	71.2	73.4

Table 4. 5-Year Cause-specific Survival Data of Low- and High-Grade Categories of
Female Breast Cancer in Missouri

Senatorial District (SD)	Low Grade			High Grade		
	<i>Rate</i>	<i>LL</i>	<i>UL</i>	<i>Rate</i>	<i>LL</i>	<i>UL</i>
1	93.8	90.6	95.9	84.0	77.9	88.6
2	94.2	90.8	96.4	81.5	74.0	87.0
3	93.2	89.1	95.8	75.9	68.5	81.8
4	90.5	86.8	93.2	75.8	69.5	80.9
5	87.6	82.3	91.3	76.8	70.3	82.1
6	90.8	86.9	93.6	77.3	70.0	83.1
7	93.1	89.4	95.5	76.9	69.3	82.8
8	91.9	87.6	94.8	77.6	70.2	83.5
9	83.0	77.8	87.1	68.8	61.5	75.0
10	91.1	86.8	94.0	79.7	71.7	85.7
11	90.3	86.6	93.0	75.7	68.0	81.8
12	91.2	87.5	93.9	76.0	67.5	82.6
13	89.9	86.1	92.7	71.3	64.8	76.8
14	91.9	88.1	94.5	77.7	71.7	82.5
15	95.2	92.5	96.9	81.7	75.7	86.3
16	90.0	85.8	93.0	80.5	73.9	85.5
17	91.5	87.9	94.1	82.4	74.4	88.2
18	90.2	86.3	93.0	75.7	68.5	81.5
19	91.9	87.6	94.8	73.9	65.8	80.3
20	95.3	92.0	97.3	77.7	70.9	83.1
21	89.6	85.4	92.7	76.8	69.1	82.8
22	94.4	89.8	96.9	77.6	69.7	83.7
23	92.3	88.9	94.8	86.3	80.2	90.7
24	92.8	89.8	95.0	85.3	79.8	89.4
25	89.1	84.4	92.4	73.7	66.9	79.4
26	91.9	88.4	94.3	77.8	71.0	83.2
27	90.8	86.7	93.7	76.8	69.7	82.4
28	91.8	88.0	94.4	81.9	76.0	86.5
29	91.5	87.4	94.3	81.2	74.7	86.3
30	91.4	87.4	94.1	77.0	70.1	82.6
31	90.9	86.6	93.9	80.9	73.6	86.3
32	92.8	88.6	95.5	72.1	65.1	78.0
33	92.0	87.8	94.8	75.4	68.4	81.1
34	89.4	85.4	92.3	78.7	69.2	85.5
Missouri	91.4	90.8	92	77.8	76.7	78.8

The reports display survival data results in two layouts: an “Area Profile” focused on displaying many indicators for one or a small number of selected districts along with results from statistical hypothesis testing; and a “Double Map” which displays two indicators simultaneously along with a district- (SDGC- or county-) level scatter-plot. These reports include combined maps and statistical data. The following screenshots show the final formats of the interactive mapping reports we built at the MCR-ARC to display Missouri FBC survival data along with other incidence and mortality data.

Figure 1. Area Profile Interactive Report Displaying FBC 5-Year Cause-specific Survival Data by Senatorial District [21]

Figure 2. Double Map Interactive Report Displaying FBC 5-Year Cause-specific Survival Data by Senatorial District [22]

District 19 and Missouri

We explored the survival data for District 19 and we compared the district's results to the state's results. The following figures show the findings.

Figure 3. FBC Survival Percentages by Age for Senate District 19 and Missouri (2004-2010)

Figure 4. FBC Survival Percentages by Race for Senate District 19 and Missouri (2004-2010)

Figure 5. FBC Survival Data by Stage and Grade for Senate District 19 and Missouri (2004-2010). [Note: “Early stage” consists of in situ and localized; “late stage” is regional and distant. “Low grade” consists of grades I-II; “high grade” is grades III-IV.]

For all races combined and all ages combined, the district’s cause-specific survival rates were higher than Missouri’s rates. For the FBC <50 year old group, the district survival rate is higher than the state’s rate. For the FBC $\geq$ 50 year old group, Missouri survival rates were higher than the district’s rates. Among whites, the district’s rate was lower than the Missouri rate. Among African Americans, the Missouri survival rate was lower than the district’s survival rate. For District 19, the survival rate among African-American women was higher than the survival rate among white women. For all stages, the district’s survival rate was higher than the Missouri survival rate. Overall, survival outcomes were higher for the district than for Missouri.

However, none of the above-mentioned differences between District 19 and Missouri were statistically significant at $\alpha=.05$

District 19 and Combined Districts 20 & 30

Figure 6. FBC Survival Percentages by Age for Senate District 19 and the Combined Districts 20 & 30 (2004-2010)

Figure 7. FBC Survival Data by Age for Senate District 19 and the Combined Districts 20 & 30 (2004-2010)

Figure 8. FBC Survival Percentages by Stage and Grade Percentages for Senate District 19 and Combined Districts 20 & 30 (2004-2010)

For all malignant FBC cases combined, District 19 had better survival rates than combined districts 20 & 30. For the <50 and 50-64 age groups, District 19 and combined districts 20 & 30 were comparable. For the 65+ age group, District 19 had survival rates lower than combined districts 20 & 30. African-Americans had higher survival rate than whites in District 19 but lower in combined districts 20 & 30. The survival rates of late stage FBC were similar between the two studied regions. Among high grade FBC cases, District 19 had a lower survival rate than combined districts 20 & 30.

After analyzing all the above-mentioned differences, we did not find any statistically significant differences between the two studied regions.

Measuring the Certainty of the FBC Cases' Address at Diagnosis Geocoding Process

As we discussed in the methodology, we assessed the accuracy of the geocoding process, which was conducted by DHSS using commercial software and measured the geo-certainty of the FBC geocoded cases. The generated maps (not shown) displayed the geo-certainty of the addresses at diagnosis of all FBC cases which were diagnosed 2004-2012 along with the types of addresses which were sent to the geocoder.

Discussion

The Missouri Cancer Registry (MCR) currently is an incidence-only registry since it lacks complete survival information. MCR needs to become a survival registry to be able to measure the impact of Missouri public health programs on survival. The measured survival rates will transform our registry from being an incidence registry to becoming a survival registry.

Survival data mirrors FBC prediction in a specific period [23]. We used the MCR records because it is a population-based registry with data that originates from diverse sources including hospitals, ambulatory surgical centers, freestanding cancer treatment centers, pathology labs, long-term care facilities, and physician offices. It also obtains cases obtained through case-sharing agreements with 19 states. MCR data go through very firm quality control standards and the data are evaluated repeatedly following specific national measures [24]. Several studies have revealed the significance of linking NDI data to central cancer registries data to confirm high quality and more accurate population-based cancer survival data [3, 4, 5].

From all the current study's results, as shown in tables 1, 2, 3, & 4, we will be able to create FBC survival profiles for the 34 Missouri senate districts. By creating these profiles, we will be able to compare each district's results to the state and to other districts' results and give more detailed information to public health practitioners and decision makers about FBC in their district.

District 19 and Missouri

The results displayed in the figures 3, 4, & 5 could be very informative for decision makers and public health practitioners. These findings might be used to explore effectiveness of current breast cancer initiatives and interventions at the district and the State level, to study impact of coverage and accessibility to screening and health care services, and to explore issues related to social inequality.

District 19 and Combined Districts 20 & 30

In figures 6, 7, & 8, we compared survival data for District 19 and the combined districts 20 & 30. We know that the compared districts are not exactly similar in population composition or in rural urban ratio, but by doing this comparison we compared FBC survival data for areas that contain two major cities in Missouri. The two largest public universities in the state are in these two cities and each city contains multiple medical facilities and specialty physicians. We assume that a large percentage of these cities' inhabitants have had easy physical access to breast cancer screening services in community health centers as well as advanced health facilities.

For both studied regions, survival data did not have a consistent pattern of differences by age or race. These findings could be very informative for decision makers and public health practitioners in both geographic areas and might enhance collaboration between decision makers to review and assess screening and treatment services to attain the best outcomes.

Mapping Reports

In MCR-ARC, we need to present our data in formats that meet the needs of a wide range of potential data users. That is why we chose to combine our survival data with geographical data to produce interactive mapping reports at the Missouri senate district level. InstantAtlas™ is an interactive, internet-based mapping tool licensed to the MCR-ARC which allows users to visually display data gathered from the registry database. Use of interactive data visualization and mapping software allows users to interact with the data sets. We built two interactive mapping reports including our Senate District level FBC survival data [21, 22]. The two maps were Area Profile Map and Double Map; we

have not publicized these maps yet on the MCR's website. The area profile report shows a single map and focuses on displaying many indicators for a selected senate district and compares the district's findings to the others and to Missouri. The double map focuses on exploring the relationships between the selected indicators. Double map displays two indicators simultaneously along with a scatter-plot or a table.

Measuring the Certainty of the FBC Cases' Address at Diagnosis Geocoding Process

To meet the goals of controlling and preventing cancer in the community, public health and cancer scientists should assess the accuracy of existing geocoding tools. With this technique, the most accurate geocoded data will be available to interested researchers, motivate geographic epidemiology research, and enhance further effective and targeted cancer control [25].

We measured the geo-certainty of the FBC geocoded cases from 2004-2010. This analysis demonstrates how the accuracy is influenced by having cases with a large proportion of addresses that are not in the city style (where the city style are addresses such as "123 E Main St"). The study investigators found that the address at diagnosis's geo-certainty and accuracy were much higher for urban and metropolitan Missouri areas than for rural areas of Missouri. The geo-certainty for FBC cases who lived in urban areas at time of diagnosis was more accurate because most of these cases have city-style addresses. This helped the geocoder to interpolate the longitude and latitude of the addresses accurately. Rural area FBC geocoding tended to be less accurate because many cases had non-city-style addresses. These rural cases were often geocoded based only on their Postal ZIP Code™ with five or fewer digits, giving poor spatial resolution. There were substantial urban–rural differences in the accuracy of geocoded data.

Accurate latitude and longitude was only needed for FBC cases in three urban areas (St. Louis Metro area, Kansas City Metro area, and Greene County) because only in these areas do senate districts not follow county borders. In the current study, we used the geocoder to determine actual senate districts of FBC cases in these urban areas. While rural FBC cases might tend to have poor latitude/longitude accuracy, for the current study, the uncertainty was acceptable since many of the rural areas have counties aggregated together; we did not need to geocode FBC cases from these regions since county at diagnosis is sufficient. The geo-certainty assessment was not an issue for SDGCs because all 20 SDGCs follow county boundaries.

Study Challenges and Limitations

During the matching processes, some cases did not have a social security number, which is the best available unique identifier. Also, some identifiers, such as date of birth and last and/or first name, showed differences when the NDI database and the registry database were compared. This may be due to data entry typos or changed last name. Such cases were manually reviewed. Manual review of all partial matches was done by more than one MCR-ARC staff member to reduce possible mistakes.

Survival rates were measured using cause-specific survival rather than relative survival (another common net measure of survival) to avoid the need of having detailed population lifetables. Potential disadvantages of using cause-specific survival are that, unlike relative survival, it relies on additionally having the cause-of-death rather than just the fact and date of death and, moreover, it relies on accurate coding of the cause-of-death [17]. To decrease the number of known decedents with unknown cause-of-death in the MCR database, these cases were included in the NDI linkage to try to obtain their

cause-of-death. To lessen the impact of miscoded cause-of-death (e.g., a breast cancer death being misattributed to the location of a metastatic site). The rates used here had defined "breast cancer death" according to the SEER Cause-specific Death Classification Recode variable [17].

Future Directions

In the future, by combining mortality and incidence data in the survival profiles, we will be able to inform every district's decision makers about the full picture of FBC burden by district and we could help them assess FBC interventions and policies on geographical bases. Due to small sample sizes, we do not have county-level results from the Behavioral Risk Factor Surveillance System (BRFSS), which is a state-based health survey that annually gathers data on health events, behaviors, preventive practices, and access to health care. A similar survey, the County-level Study, was done on the county level in Missouri [26]. In the future, we could combine these results to the survival data and create InstantAtlas™ mapping reports including survival and other measured contextual indicators. This kind of mapping report could be used to explore the relationship between FBC and other measured contextual indicators all over Missouri.

In this paper, we measured 5-year cause-specific survival rates of FBC for the 34 senate districts in Missouri. In the future, we will consider the feasibility of measuring the same rates for all 163 Missouri legislative districts [27, 28].

Conclusions

Net measures of survival factor out other causes of death and are useful from a policy-based perspective. These measures enable comparisons of cancer survival across

geographical regions and between groups of patients without differences in background rates of other causes impacting the results.

Cancer registry data is very rich and can be used in exploration of many scientific theories and models. Registry data could be a valuable source to get survival rates of breast cancer cases by race, age, and stage at diagnosis. Using cancer registry data supplemented by SSDI and NDI information will be beneficial and could improve accuracy of breast cancer survival by age, stage or race as well as by geographic area (counties and senatorial districts).

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CHAPTER III: Assess the Usability of the Missouri Cancer Registry and
Research Center's (MCR-ARC's) Published Interactive Maps and Profile
Reports

Geographic Information Systems: Usability, Perception, and Preferences of Public Health Professionals

Abstract

Background: Analyzing and visualizing health-related databases using Geographic Information Systems (GISs) becomes essential in controlling many public health problems.

Objectives: To explore the perception and preferences of public health professionals (PHPs) about the usability of GISs in public health field

Methods: A scoping review. The investigators searched Medline Ovid and PubMed databases for The following key- terms 1) Geographic Information System (GIS) OR GIS OR mapping software, AND 2) public health OR public health practitioners, AND 3) usability OR functionality OR utility OR perception OR, preferences. The search resulted in two articles. The PubMed was searched with the same strategy and did not produce any results. The investigators tried to search the key- and MESH-terms differently using PubMed database and found a usability article which is strongly related to the current study aim. The investigators searched the related articles of that study and got 55 strongly related articles. Finally, nine articles met the review's inclusion criteria.

Results: Iterative evaluations, extensive training, and involvements of GIS end users are productive in GIS usability. More methodologies are needed to support the validity of GIS usability studies. The exchange of GIS technology impacts public health policy and research positively.

Discussion: PHPs are aware of the use of GISs in public health field, and exchange of the visualized health-related in determining the inequalities and inaccessibility issues.

Conclusion: GISs are essential to control public health problems if the related health datasets analyzed carefully and if the mapping reports extensively evaluated and interpreted.

Keywords: Geographic Information systems, GIS, Public Health, Usability

Introduction

Public health work requires collaboration and effective communication between public health team members [1]. Therefore, the Geographic Information System (GIS) tools should be designed to meet the needs and perspectives of the team members. The problem today is not in creating new GISs, but in effective and efficient use of the existing ones [2, 3].

Analyzing and visualizing health-related databases, using sophisticated statistical software, is essential in helping control many public health problems in any community. This data should be handled carefully and analyzed adequately to get reliable results and not mislead the target audiences [4].

Most of the potential users of the health related spatial data find difficulties in interpreting statistical and mapping information of most health-related spatial reports [5,6,7]. The major issues are the lack of experience and training to use this technology, lack of acceptance to use GIS tools, and the complicated design of the most existing GIS technology [8]. Providing the potential users of GISs software with clear explanations on

the statistical methodology and results, analogies of the combined diagrams and maps will enhance the users' understanding and motivate them to use this technology [9].

Mapped public health data can create knowledge, produce evidence, and generate policies [10]. Every mapping report should carry a specific purpose and a clear message to the audience [11]. Targeting the Public Health Professionals (PHPs) and policy makers, the mapping reports should include citations of the used databases' sources and the methodology of the results. In order to make it user friendly, the usability of the GIS tools and reports should be iteratively tested using pilots of the potential users before and after tools' release [4].

Current literature proves the collaboration between the professionals of the same public health interest through linking health information from different sources through designing portals and applications [12]. This will help guide PHPs and policy makers to develop cost-effective public health interventions [12]. Over the last 20 years, spatial health data are transformed from being static to being interactive and dynamic [13].

GIS tools could help in communication between experts in different fields, and the GIS developers and users should consider technical, social, and cultural issues during development, evaluations, and the updating of the GISs tools to enhance the experts' connection [14]. The investigators of the current scoping review could not find previous literature reviews adopting the same aim, including all of this review's inclusion criteria (see methods section), covering exactly the time limits of this review, and/or using the same searching strategies and the similar keyword terms used in the current review.

The current scoping review's aim is to explore the perceptions and preferences of public health practitioners and policy makers about the use of GISs in public health practice, and to search the literature about the usability and utility of GISs in public health fields.

Methods

Study Design and strategy

The study design was a scoping review research. The investigators searched for eligible journal articles in the following databases: Medline Ovid and PubMed databases. The following key- and MESH-terms were searched using Medline Ovid: 1) Geographic Information System (GIS) OR GIS OR mapping software, AND 2) public health OR public health practitioners, AND 3) usability OR functionality OR utility OR perception OR, preferences. The search resulted in two articles. The PubMed was searched with the same strategy and did not produce any results. The investigators tried to search the key- and MESH-terms differently using PubMed database and found a usability article which is strongly related to the current study aim. The investigators searched the related articles of that study and got 55 strongly related articles. Finally, nine articles met the inclusion criteria (Figure 1)

Figure 1: Search Strategy Flow Chart

Inclusion Criteria

Eligible articles for this review were written in English, published in the years from 2000 to 2016, and included usability interviews or usability testing of public health professionals (PHPs) and/or decision- or policy-makers. In the usability testing literature,

the studies test the usability of: GISs, mapping atlases, mapping applications, or spatial or spatial-temporal websites and/or portals. These mentioned tools should display spatial or spatial-temporal public health data. In the usability studies, the inclusion criteria for the users were public health practitioners or professionals, epidemiologists, public health program directors, spatial reports developers and analyzers, and public health policy makers.

According to the study design and the methodology, we divided our selected articles into:

1. Articles based on usability testing of GIS tools, applications, and or websites display spatial-temporal data: Four articles met the study inclusion criteria.
2. Articles based on interviewing PHPs and policy-makers to find out their GISs' perspectives and preferences in public health field: We have five eligible articles in this category.

Results

The results of the nine eligible articles were not comparable because: the participants were different (demographics, experience, work type, and degree of education), they were testing different GIS software and they were interviewing participants using different research measures. See Table 1 and Table 2.

Usability Testing Studies:

Usability Testing Studies Based on Testing GIS Tools by Participants:

There are four articles in this category. The important information about the studies was extracted and presented in Table1.

Table 1. Usability Testing Studies Based on Testing GIS Tools by Participants

Author	Year and Country	Aim	Study Design	Methodology	Main Findings	Recommendations
Rhobinson et al	2007/USA	To assess how epidemiologists perceive and use GIS technology in their daily practice, and testing the usability of a GIS tool used to present and visualize multivariate health data	Mixed Methodologies. User centered design method. Iterative evaluations	In 2003: A graduate students sample conducted card sorting and verbal protocol analysis. 2004 (a): Cancer seasoned epidemiologists (actual tool's end users) conducted protocol analysis and focus group activities. 2004 (b): Case study to investigate the studied tool in collaboration with epidemiologist for several months. 2004 (c): Five expert epidemiologists participated in Individual user task analysis to test usability of the refined system	2003: Shifting to the actual tool's end-users will be better to test the tested tool. 2004(a): The tool was tested by the actual end users. 2004(b): the collaborated epidemiologist brobed many usability issues of the tool, was a successful case-study. 2004 (c): based on the previous stages' results, the users focused more on the tasks rather than the interactions. It was a successful iterative evaluation steps to refine the tested tool	Functionality and utility of any tested tool are much important as the user-interaction of that tool. Iterative and mixed methodology evaluations should be conducted to assess any GIS tool. The actual users must be involved in the usability study of GIS tools. Usability should be evaluated extensively before releasing the tool to the actual users. Case study evaluation is very fruitful to assess any tested tool.
Bhowmick	2008/USA	To test usability and utility of Pennsylvania Cancer Atlas (PA-AT) using Delphi application to further update the software	Mixed Methodologies. Iterative user-centered design. Usability testing, focus groups and surveys.	Stage 1: (2 groups) GIS science graduate students (n=7) and cartography and information visualization experts (n=4). Stage 2: (2 groups) epidemiologists (n=7) and spatial analysts and state public health professionals (n=7). Stage 1 & 2 had 4 rounds	Best reports included tables, maps, and graphs for cancer control professionals. Difference in experience is obvious in dealing with the reports. The authors concluded some advantages and disadvantages of web-based questionnaire and communication with study participants. The results of the assessment were positive from both stages as following: improving interaction function, enhancing methods of temporal analysis, addressing data issues, providing additional displays and help utility of the atlas. This research demonstrated the potential of distributed web-based tools to support group input to health geographic tool design.	To continue improve the design of the PA-CA, the investigators should continue considering the end-users and make further evaluations. It is important to get feedback and suggestions from end users of different experience
Cinnamon et al	2009/Canada	To test usability of different kinds of the geo-visualization maps	Mixed Methodologies. Usability testing of static, interactive, and animated maps of injuries developed after needs asesment and map designing	The injury and socio-demographic data were mapped and uploaded to a developed website. Eight Participants from different public health backgrounds are participated in the usability testing sessions. On site, usability testing sessions were conducted with just an assistant to observe and write the participants' comments and interactions. The sessions followed by a questionnaire to be filled out by participants. The usability study was ended by short discussion about the sessions and the tested maps	Different maps are useful for different purposes and for satisfying the varying skills of the users. Static: versatile and easy to use. Animated: more effective. Interactive maps are the most preferred maps to compare patterns of injury and sociodemographic risk factors. Most of users agreed on time, cost, experience in map analysis, and availability of right data as limitations to use maps. All participants are strongly agreed on maps as useful tools in prevent and control injury prevention	Any geographic visualization techniques that could be applied to public health should be tested. To validate any usability testing study results, different profiles of end-users should be tested using control groups.
Koenig	2011/UK	To conduct a pilot study exploring preferences and perspectives of the public health practitioners regarding the internet-based and interactive geo-visualization technology and tools.	Usability testing using a convenience sample of PHPs using structured human-computer interaction face-to-face interviews.	Seven academia based PHPs were interviewed. The participants were categorized as novice, intermediate, Experts. Five sections questionnaire: user experience, diverging color schemes, classification schemes, graphical representation, interactive mapping. A structured interviews to assess the participants' understanding of GIS morbidity data were conducted. The questionnaire also tested the participants' visualization preferences of the GIS technology.	Novice participants faced difficulties in interpreting the sophisticated mapping and statistical information of the tested interactive GIS material. The novice participants also struggled with making links between the cartographic and the associated statistical information.	Novice PHPs will benefit from an extensive interpretation of the interactive mapping methodology, sources, and results. The interpretation should not be just through sophisticated technology, but also through increasing the interaction between PHPs and mapmakers. This will enhance PHPs and public health policy makers to adopt GIS technology in public health problems' prevention and control.

The first study was conducted by a geography scholar. The study's objective was to explore how the epidemiologists take advantage of the geo-visualized technology, and how they expect this information to help them in practice. The study design was usability testing of the Exploratory Spatial-Temporal Analysis Toolkit (ESTAT) which visualizes multivariate health data to support cancer epidemiology. The study was user-centered and the researchers conducted iterative evaluation processes to refine ESTAT.

The study design was multi-staged. In the first stage: This stage was conducted on graduate students using card sorting and verbal protocol analysis types of evaluation. After a year, the study investigators shifted to the actual end-users after they had problems with some tool's interface. In the second stage: The researchers carried verbal protocol analysis on 12 epidemiologists followed by focus group activities to discuss the testing usability sessions. Verbal protocol is defined as: "A psychological research method that elicits verbal reports from research participants" [15]. In the third stage: A case study by collaboration with an academic epidemiologist to analyze ESTAT. His analysis was a positive addition to the tool's design. In the fourth stage: Five experts in data analysis tested the refined tool using verbal protocol analysis followed by focus groups. Scatter plot was the first analytical measure the epidemiologists used followed by bivariate map tools. The complicated and multivariate tools of the ESTAT were not used commonly with the users. The most interesting finding of this stage was that the users did not face a lot of interaction problems, and this indicated improvement in development and refinement of the tool [16].

The second study was conducted by scholars from four different specialties and expertise: public health, geography, clinical medicine, and cancer research institute. The study objective was to test the usability and utility of the Pennsylvania Cancer Atlas (PA-CA) to refine the software. The study design was multi-staged user-centered evaluations of PA-AT usability using web-based application (Delphi application). In the first stage: The investigators tested the PA-CA using two groups of users. The first group included seven GIS science graduate students, and the second group formed from four cartography and information visualization experts. Second stage: Included two groups, seven

epidemiologists in the first group, and seven spatial analysts and Pennsylvania state public health professionals in the second group. Every stage of evaluation had four rounds of testing sessions. The professional participants pointed out that the best spatial reports included tables, maps, and charts. The responses and the using of the tested spatial reports were varied by the difference in expertise. Most of the participants stressed on the importance of integrating tutorials and help information for the PA-CA end-users. The results of the evaluation processes were totally positive. The testers came up with important recommendations on the PA-CA software: improving user-software interface and motivating new methods of temporal analysis. The other main finding of the study was the ability to distribute web-based tools to access different kinds of experts and recruit them to test the design of GIS tools [17].

The third study was conducted by researchers of different scientific backgrounds: geography, medical school, and public health specialties. The study design was multi-staged. First stage: There was a user needs assessment through meetings with public health stakeholders who described the need for injury related GIS tools and reports. Second and third stages: Which is named as the map development stage. Three map types were created by the researchers. The maps were: static, animated, and interactive maps. The created maps displayed the injury data and its socio-demographic determinants. These maps were uploaded to a developed website. Fourth stage: The uploaded maps were tested using a sample of public health officials and injury prevention stakeholders. The usability testing sessions were on-site with an observer to write down the users' comments and their map-interface. The sessions were followed by a self-filled out questionnaire and short discussion per participant. All the participants revealed that all

map types are useful for different purposes. Most of them pointed out that the animated maps are more effective than the static maps, and the best maps to effectively compare the injury data to its socio-economic determinants were the interactive maps. Most of the users agreed on the effect of the resources in terms of time, money, expertise on the map development industry, and the availability of right and appropriate data to build successful maps [18].

The fourth study was carried out by three scholars from different specialties and educational institutions: Public health science, environmental and engineering science, and geography science. The study aims were to conduct a pilot study on a sample of PHPs to explore their comprehensive and visualization preferences of the interactive online-based mapping reports, and to evaluate the effectiveness of the interactive mapping reports' formats and measure the actual end-users' interactions with the tested GIS tools.

The study design was built firstly on a five sections interviewing questionnaire. The test was on-site, face-to-face, and a GIS-based interview. The interviews were accompanied with direct observation and think-aloud protocol. The participants were asked to examine the tested visualization material, answer the questions, and write down their preferences, perceptions, and expectations on the tested material. The recruited seven academia PHPs were assigned according to their expertise of using disease visualization maps, based on their answers on a specific question to: Novice, intermediate, and expert categories. The interviews included five sections in a well-structured questionnaire: -user experience, diverging color schemes, data classification schemes, graphical representation of morbidity data, and interactive mapping usability tasks. The novice participants had

problems in exploration of the data classifications, in understanding the supplementary sophisticated statistical graphics, and in linking the interactive tables with the maps of the tested reports. There were differences in the perception of the interactive mapping reports among the participants according to their previous geographic experience [19].

Usability Studies Based on Just Interviewing the Participants:

There are five articles under this category. The articles' methodologies were based on interviewing PHPs, cartographic scientists, map developers, and/ or public health policy makers. See Table (2).

Table 2. Usability Studies Based on Interviewing the Participants

Author	Year and Country	Aim	Study Design	Methodology	significant findings	Recommendations
Ghetain et al	2008/USA	To evaluate usability and utility of GIS technology this is used in cancer research and policy	A phone interview based usability Study	the participants recruited through email invitations. 49 of 50 States' Cancer Control directors were interviewed about the use of GIS in cancer research and policy	According to the participants responses: (1) Advantages of using GIS in cancer policy: identify services inadequacy, explore accessibility, knowing population at risk, and classifying cancer staging. (2) Research advantages: monitoring and surveillance, important statistical and cartographic resources, generate research questions and hypotheses (3) Relation between mapped Behavioral risks data and perceived advantages: There were significant relationship between using behavioral risks mapped data and only the determination of at risk population policy. (4) Cancer incidence, mortality, and staging there was no significant relation of this mapped data to cancer policy, but it was significantly related to producing etiology hypotheses research advantage. (5) Environmental Exposure: No significant relation of this mapped data to any policy or research advantages. (6) Health care services: There was significant relation of this data to accessibility policy. (7)Transportation Access: There is significant relation to accessibility policy as well as significant to generating etiology hypotheses.	(1) The government must encourage the updating and use of diseases registries' databases in mapping reports and help connect health research with politics environment (2) The GIS use depends on training the potential GIS end-users and disseminate the GIS technology. (3)Policy makers should be involved in health related data development, analysis, and GIS use (4) the policy makers should be motivated and educated about the importance of the GIS use in practice.
Rhobinson et al	2011/USA	To test and refine the online tool was developed to join and communicate the geovisualization and map developers experts	Online needs assessment survey with targeted end-users	The sampled public health professional participants were probed about the tested tools learning artifact	Current learning Habits: Most of the participants spend <10 hours learning on new tools. Some of them were asked to learn by the employer. The net, journal articles, scientific conferences, and asking others were good ways to learn. Searching the net is the common way which is used by them find tools' learning artifacts. Other co-workers are better than employers in offering information about tools. Most of them admitted the importance of GIS use in practice. Preferred learning artifacts: Most of participants preferred having extensive tutorials and sessions on GIS technology's content, summary, functionality, and usability. >560% want to know the bio-sketch and the credentials of the learning artifacts' developers. The artifact content and the summary are the most important parts, and the metadata was the least required thing. Contributing Learning artifacts: Wikipedia, YouTube, and Facebook were the most important resources of learning. Almost all of the participants agreed on the importance of the learner's bio-sketch and credentials in motivating them to apply the artifact in practice.	The GIS tools end users should be involved in designing and development of the learning artifacts of these tools through needs assessment surveys
Bhowmick et al	2008/USA	To develop and test the new geographic information technology and tools to analyze and visualize the complicated health datasets in public health field	Key informant interviews on the use of GIS technology followed by a systematic review on the related literature	Sixteen cancer research experts were recruited through snow ball sampling technique. Semi-structured phone interviews were conducted using focused discussion and ACT-based representation of Knowledge (ARK) techniques. The GIS non-users were studied to find the barriers to use the GIS technology.	The participants had different demographic, experience, and scientific backgrounds. Most of them were cancer research experts. Most of them pointed the importance of GIS in detect dataset features, generate hypotheses, and to discover roles of GIS in cancer dataset exploration. Most of them did not use sophisticated GIS technology, but some of them they mentioned a geospatial rules as routine work. The GIS technology use was recognized from moderately to a very useful in cancer research field.	Usability testing studies are more productive than just interviewing public health practitioners or reviewing literature. In depth interviews of a small size samples are more productive than interviewing large samples in less depth. Collaboration between the information domain experts and the implementation experts is very important.
Joyce	2009/UK	To assess the perception of the public health policy makers about the GIS use in public health field, advantages and disadvantages of GIS in public health field, and considering GIS technology as away of collaboration and exchange information	Semi structured interviews	Face to face interviews of 23 PHPs participants, who were chosen based on specific selection criteria.	GIS technology a producing knowledge, able to integrate and analyze databases. There are challenges to use GISs. GIS includes temporal-spatial information could search cause-effect theories. GISs are crucial for communication and collaboration between experts of the same interests. The linkage and willingness of sharing GIS technologies must be strengthened further. Most of the GIS end users afraid of the GIS complicated functions. GIS output impacts realities by relating the findings to real life parameters and could affect policy makers' points of view. GIS in information could be manipulated and misinterpreted.	GIS tools becomes crucial in practice. The users should be helped and trained to adopt use the GIS in practice. GIS likely to be most effective in decision-making when applied in a multi-disciplinary context to facilitate sharing of data, knowledge and expertise across the public health landscape.
Higgs	2005/UK	To search the types of organizational barriers to the fruitful operation of GIS within the National Health Services (NHS) in UK, and compare the findings to the previous related literature	National survey followed by in-depth semi-structured questionnaire, followed with a systematic review	Grounded on a national questionnaire results, the researchers conducted semi-structured interviews of 20 NHS personnel. The interviews including these factors: individual issues, policy issues, data issues, organizational issues, and various resources issues.	GIS use and implementation: increase of GIS use after the survey's conduction. Geospatial reports production and analysis are important in practice. Examples GIS uses: inequalities, accessibility, environment sciences. About half of the interviewees did not fully run their GIS. Information Technology administration and maintaining systems are essential to enhance GIS usability. GIS implementation barriers: lack of electronic datasets, complicated GIS tasks, scarce trained resources, lack of maintenance systems, lack of clear organizational plans and goals, absence of external and central leadership on GIS, lack of alertness among clinicians and administrators of GIS technology. Levels of geographical information exchange: issues with certifying measures for data, inappropriate datasets, bad marketing of GISs, inappropriate interoperability between organizations.	The collaborated organizations which are tackling health issues should modify their cultural and organizational policies, to be able to exchange the health-related geospatial data. This needs expert advice and guidance.

The first study was conducted as a collaboration of three geography scientists from three different universities. The aim of the study was to analyze the important organizational issues which are important to successfully implement GISs within National Health Services (NHS) in the UK and compare the results to previous studies that were conducted to analyze the same aim. The study design was mixed-methods, starting with a national questionnaire followed by semi-structured interviews. The national questionnaire was formed on the current use of GIS software; future plans for GIS use; policy related uses of GIS; the barriers of using GIS; enumerate human, environmental, and organizational barriers to implement GIS. The questionnaire was answered by health services professionals. An in-depth interview was conducted on 20 selected NHS personnel. The interviews included the potential issues to establish GIS software, individual issues, policy issues, data issues, organizational issues, and various resources issues. The national survey revealed an increase of GIS use, map production and GIS use in analysis, modeling, and data integration are important. The examples of GIS uses were in: inequalities, accessibility determination, and environmental sciences. Less than 50% of the interviewees stated they did not fully operate their GISs. Informational technology administration and maintaining systems are influential for GIS implementation. Both the survey and the interviewees stated a list of the obstacles to GIS implementation: lack of digital data, difficult analytical tasks of GIS, lack of staff resources to operate GIS, lack of GIS skills, lack of maintenance systems, lack of wide organizational planning, lack of authority's awareness, insufficient training of the GIS users, lack of central plan and support from the department of health to its organizations, and lack of awareness among clinicians and administrators of the GIS importance. The respondents were asked about

the barriers and issues which restricted the geographic information exchange, the responses were varied: Licensing arrangement issues between the organizations, presence of GIS data in specific formats, lack of interest of GIS exchange in other organizations, and hard- and soft-ware incompatibilities among different organizations [20].

The second study was conducted by three communication and art scientists, and a public health scientist. The aim of the study was to evaluate the use and the utility of GIS tools in mapping cancer related data and their effect on cancer control policies and practice, and to measure the participants' perception on using such tools in the Comprehensive Cancer Control (CCC) program. The researchers recruited the participants through email. Forty-nine U.S. CCC program directors out of 50 states were interviewed by phone. The interview questions were to explore the relationship of GIS reports to public health policy and research. The identified advantages of using GIS on cancer policy were: Identify service gap, identify access issues, identify cancer staging, followed by identify risk population. The identified advantages of using GIS on cancer research were: multivariate modeling tool, monitoring and surveillance, followed by generate etiologic hypotheses. There was no significant relationship discovered between using behavioral risks mapped reports and research, while there was a significant relationship between behavioral risks mapping data and the policy of identifying the at risk population. The study did not discover any significant relationship of cancer burden mapped reports and cancer control policy, but there was a significant relationship of this kind of mapped reports and the generating etiology hypotheses research advantage. About 51% of the interviewed directors stated that the demographics are an important content of any mapped reports, but the study researchers could not find any significant relation of the

demographics to any of the policy and research advantages. There was significant relation of mapped reports of transportation access and the accessibility policy, and the etiology hypotheses research advantages. There were no significant relations between policy and research, and all of these kinds of cancer mapped contents: Environmental exposure, multi-layer content maps, and healthcare services [21].

The third study was conducted by scientists from the geography, environmental science, and public health fields. The aim of the study was to develop and evaluate the tools and methods that might be used by PHPs in order to extract knowledge and evidence from health-related databases. The methodology of the study was semi-structured phone interviews of 16 participants who were recruited using snowball sampling. The investigators searched the literature of using GIS in cancer research to support the interviews' results. The study findings were: Most of the participants were faculty or senior administrators of different demographic and scientific backgrounds. They varied in experience. Most of the participants were involved in the cancer research domain. Most of the participants pointed that the typical goal of data exploration were to detect dataset aspects, to develop hypotheses for further cancer research, and to discover roles of geospatial methods in the exploration process. Most of them did not use complex spatial analysis, but 30% of them reported geo-coding, map creation, and GIS data analysis as regular research activities. GIS analysis were considered from moderate to very useful tools in cancer research, specifically in incidence and mortality cancer data. They pointed to the importance of GIS in comparing spatial data of different cancer types, disease clustering, correlation with related spatial indicators, and combining geospatial data from different domains. The participants pointed to the following limitations in GIS use:

difficulties in geo-coding and data aggregation, lack of support for merging data from different data sources and/or constructed with different GIS tools, complexity of GIS tools use and functionalities [22].

The fourth article's aim of the study was to study public health professionals' perceiving of the GIS in practice and research and understand the impact of GIS on data sharing and communication. The methodology was face-to-face semi-structured interviews of 23 participants of policy decision makers. The participants were recruited purposefully. The article findings are: GISs are converting raw data to useful data and knowledge. GIS has the ability to integrate and analyze datasets. GISs are important in public health practice and decision making, but include many implementation and usability challenges. GIS could be used to explore cause-effect relationship by including time and space, and have epidemiological power. GISs are crucial for collaboration between experts of the same interests but there are challenges to that. The linkage and willingness of sharing GIS technologies must be strengthened further. Most of the low experiences in GIS use of public health practitioners are fear of the sophisticated functions of the GIS tools. GIS output impacts realities and could affect policy makers' decisions. Some participants pointed that GIS tools are not neutral and map makers might manipulate datasets using GIS power. Metadata and detailed text are very important to interpret the GIS data. Data quality is very important as well as strict standards during constructing GIS data. GIS tools are considered user-friendly, and easier to relate data tools. Time and resource constraints, training skills, and intra-organization environments enhance feelings of insecurity and concern among potential GIS end-users [23].

The last article's aim was to conduct a needs assessment survey on the potential end users of the Geo-visual Explication (G-EX) Portal, an online tool was designed to connect researchers in geo-visualization to the end users, to refine the G-EX Learn module. The researchers developed a web-based survey using their previous in-depth usability studies. The participants were recruited by sending them emails. There were 21 participants from different back grounds: Epidemiologists, health policy specialists, geographers, and research scientists. The results were as follows: Most of the participants spend less than ten hours per week learning new tools and 20% of them were required by their employers to keep learning these tools. The ways of learning about new tools were: the net, journal articles, conference sessions, and asking colleagues. The least likely way participants learned about these tools were advertisements and employer contribution. The participants' preferred learning artifacts were comprehensive tutorials followed by hands on training. Most of the participants wanted the artifacts to include: expected training duration, summary of learning objects, and they preferred to start using the software before starting the training. 63% of the participants liked to know the biography of the trainers. Most of the participants spotted that the artifact's content, summary, and the instructions are the most important parts of any learning module. The other contributing artifacts for the participants were: Wikipedia, YouTube, and social media respectively. 52% of them were interested in development training material to share with others on the G-EX website [24].

Discussion

The findings of the reviewed articles are discussed separately as they were classified in the methods and the results sections.

Usability Testing Studies:

It is important to include a representative sample of the actual users in any usability testing of any GIS tool. A five participants study is able to demonstrate most of the usability problems of the tested material [25]. This enables the investigators to measure the actual user- tool interface and helps them successfully design, implement, and refine these tested tools. All the studied usability testing articles used the actual users to test the GIS systems. The review also revealed that the usability testing research should extend to explore the content, functionality, and the utility of the GIS tools. The review stated that any GIS tool should be iteratively evaluated using different methodologies. The review discovered that case studies by collaboration with experts were very valuable in refining and development of GIS tools. The review concluded that visualizing the health-related data in an interactive way including tables, maps and graphs is considered the best way to present such information. The review revealed the importance of the development of online applications to access more potential users and help them participating in testing the GIS tools. The review stated that building successful mapping reports depends on the availability of: monetary support, right data, and expertise in map construction. The Review pointed that the level of experience in using visualization data is critical on willing to use GIS software, and on interpretation and linking of the mapping reports' information.

Usability Studies Based on Just Interviewing the Participants:

The review revealed that even to assess the PHPs' preferences and perspectives the researchers do not have to rely on just interviewing the participants, but they have to search for more methodology to support their results validity. Some of our reviewed articles supplemented their interviews with the results of well-respected national questionnaire, and some did systematic reviews to support the study evidence and generalizability.

Health organizations should assess and overcome the organizational, cultural, technical, and expertise barriers to implement and use GIS software to visualize their data. One of our reviewed articles recommended the adoption of policies that support visualization of health related data on the state level, and valued the importance of state encouragement of utilization and presentation of disease registries on geographic bases to connect health research to the political environment. All of the reviewed articles pointed to the importance of dissemination of successful GIS technology, training the potential users adequately, giving up-to-date information technology administration support and maintenance. Most of the reviewed articles recommended involvement of policy makers in using GIS tools and in analysis of the GIS tools results. The review recommended collaboration between GIS software developers and implementers and the potential end-users to develop new- and test the refined- versions of public health GIS tools.

The review articles in this section revealed that needs assessment is crucial to know the perspectives of the GIS potential users and to develop web learning portals and modules. The review suggested that the learning artifacts of GISs tools could be presented in different formats based on users' preferences. The review recommended that employers

must offer extensive training for their GIS potential users before and after implementation of the GIS tools.

Conclusion

In general, the review revealed that PHPs are alert about the importance of using GIS software on public health policy and research. Most of the studies' participants pointed to the advantages of using GISs on public health practice in determining the inequalities, accessibility, and they stated the importance of supplementary roles of other contextual indicators on different public health problems when these indicators are visualized with the health-related data.

Most of the studies revealed the participants were aware of the collaboration and the exchange of the GISs technology and data between the experts in the public health field, and the importance of including the end users in the basic stages of designing and development of the GIS tools. Also, the importance of extensive evaluations for GIS tools before and after releasing them, and the essentiality of adequate training for the potential users of these GIS tools.

Review Limitations and Future Directions

The review's authors searched a limited number of data bases, used strict inclusion and exclusion criteria, and used the literature which published in a limited period of time. Future usability testing studies must include more potential end users who must be recruited randomly and tested using more sophisticated methodology and more strong qualitative as well as quantitative measures.

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Usability Assessment of the Missouri Cancer Registry's Published Interactive Mapping Reports: Round one

Abstract

Background: Many users of spatial data have difficulty interpreting information in health-related spatial reports. The Missouri Cancer Registry and Research Center (MCR-ARC) has produced interactive reports for several years. These reports have never been tested for usability.

Objectives: To conduct a multi-approach usability testing study to understand ease of use/user friendliness/satisfaction and to evaluate the usability of MCR-ARC's published InstantAtlas™ reports.

Methods: Study Design: An Institutional Review Board (IRB) approved mixed methodology usability testing study using a convenience sample of health professionals.

Participants: A recruiting email was sent to faculty in the Master of Public Health Program and to faculty and staff in the Department of Health Management and Informatics at the University of Missouri-Columbia. The study included seven (7) participants. **Study Procedure:** The test included a pretest questionnaire, a multi-task usability test, and the System Usability Scale (SUS). Also, the researchers collected participants' comments about the tested maps immediately after every trial. Software was used to record the computer screen during the trial and the participants' spoken comments. **Measured Outcomes:** Several performance and usability metrics were measured to evaluate the usability of MCR-ARC's published mapping reports.

Results: Six of the ten assigned tasks reached a 100% completion success rate, and this outcome was relatively related to the complexity of the tasks. The simple tasks were handled more efficiently than the complicated tasks. The SUS score ranged between 20-100 points, with an average of 62.7 points and a median of 50.5 points. The tested maps' effectiveness outcomes were better than the efficiency and satisfaction outcomes. There was a statistically significant relationship between the subjects' performance on the study test and the users' previous experience with Geographic Information System (GIS) tools ($P = .03$). There were no statistically significant relationships between users' performance and satisfaction and their education level, work type, or previous experience in healthcare ($P > .05$). There were strong positive correlations between the three measured usability elements.

Conclusion: The tested maps should undergo an extensive refining and updating to overcome all the discovered usability issues and meet the perspectives and needs of the tested maps' potential users. The study results might convey the perspectives of academic health professionals towards GIS health data. We need to conduct a second round usability study with public health practitioners and cancer professionals who use GIS tools on a routine basis. Usability testing should be conducted before and after releasing MCR-ARC's maps in the future.

Keywords: Geographic Information Systems, Health Professionals, Interactive Maps, Missouri Cancer Registry, Usability.

Introduction

Geographic Information System (GIS) tools should be planned to achieve the desires and perceptions of these tools' targeted users. The development of GIS tools does not seem to

be an issue; the problem is in how to ensure that existing tools can be used more effectively and efficiently [1, 2].

Health care and public health fields have started using sophisticated technology to analyze and visualize health-related data. Advanced visualization technology is becoming essential and important nationally and internationally to help control many health-related problems. This technology has positively impacted health-related research and policy development. Therefore, these databases need to be held wisely, investigated sufficiently in order to produce consistent results, not mislead the audiences, and produce the expected impact [3].

As the previous literature has pointed out, high percentages of any new digital technology's potential users find difficulties in interpreting and understanding the complicated and combined information [4, 5, 6]. For the GIS tools where statistical and spatial information are combined, the tools' users have faced the same difficulties. Several reasons have been identified: inadequate experience and training on how to use this technology; lack of awareness among potential users; refusal to use this kind of technology; and because this technology is often vague, complicated and not user friendly [7].

Static and interactive health-related mapping reports could generate knowledge, yield proof, and enhance policies [8]. Each interactive mapping report should convey an unambiguous purpose and transmit a flawless meaning to the addressees [9]. Targeting the health scientists and decision makers, the health-related maps should embrace references of the used data resources and the approach which was used to get the mapped

results. The usability of the health-related mapping reports must be accordingly scrutinized and assessed using a representative sample of the potential users before and after releasing the maps [3].

The current scientific literature supports the importance of cooperation between public health scientists and health professionals in integrating health information from diverse sources via portals and applications. These systems can guide public health professionals in designing and developing useful public health policies and interventions [10]. Over the last two decades, the mapping reports have transformed from being static to being dynamic [11]. GIS users prefer interactive reports over static and animated ones [3]. The same literature encourages map developers to consider the practical and social issues of users during development, evaluations, and updates of GIS tools [12].

Many cancer registries have started interactively mapping their databases' results but few of them are assessing the usability and functionality of this technology [13, 14, 15, 16, 17]. We are seeking to fill this gap and give an exemplary model to help other registries to conduct usability testing studies to tailor their visualized and mapped material according to their possible users' perception and preferences.

This study was the first usability study to assess the quantitative and qualitative metrics data from the sampled health professionals while they are interacting with the published MCR-ARC InstantAtlas™ mapping reports. The investigators conducted a multiple methodology usability testing study of the published interactive mapping reports of the Missouri Cancer Registry and Research Center (MCR-ARC). The goals were to understand the ease of use/user friendliness/satisfaction of the maps, and to measure their

effectiveness and efficiency using a convenience sample of health professionals. These maps had been implemented with InstantAtlas™, See Multimedia Appendices 1 and 2 [18, 19]. The study aims to refine the registry's published reports to increase the satisfaction of their professional end-users. The investigators also want to assess whether and to what extent, the users' performance will be affected by their demographics, experience, education level, and type of work.

Methods

Study Design

The investigators chose a mixed methodology approach. The tested reports had been published on the MCR-ARC website [20]. The researchers conducted a pretest questionnaire, a multi-task usability test, and the System Usability Scale (SUS) for every participant [21].

The Pretest Questionnaire

The questionnaire included questions on every participant's work type, personal information, total experience in the public health field, experience in use of GIS tools, years of practicing public health, and the participant's education level (see Multimedia Appendix 3). This step was followed by the multi-task test.

Multi-task Usability Test

The multi-task usability test was composed of ten individual tasks, which were applied on the tested mapping reports. These tasks were performed by the participants to diagnose the usability of the tested reports. Based on the published mapping reports functionality, the multi-task usability test was constructed by the study investigators to measure the

efficiency and effectiveness of the tested reports. The tasks were in the same order for all participants (see Multimedia Appendix 4). There were ten because these assigned tasks covered most of the maps' functionality. By conducting all these tasks effectively and efficiently, the users could reach the designer's expected beneficial of our visualized data

The System Usability Scale (SUS)

The System Usability Scale is an industrialized and simple ten-item scale to measure the participants' subjective evaluation of the tested mapping reports' usability. The SUS was conducted immediately after the completion of the multi-task usability test. The SUS scores range between 0 and 100. Scores above 68 points have been counted as acceptable according to usability literature and higher scores represent the optimal to best score [21].

Participants

The study's proposal was approved by the Health Sciences Institutional Review Board (IRB) of the University of Missouri-Columbia. Recruiting emails were sent to faculty in the Master of Public Health (MPH) Program and faculty and staff in the Department of Health Management and Informatics (HMI) at the University of Missouri-Columbia.

Using a convenience sample, investigators ran the study's trial on the first seven potential respondents who agreed to participate. The minimum number of participants needed to conduct a successful usability study is five; a five-participant study will be able to demonstrate between 55% -100% of the usability problems of tested material [22, 23]. In this study, we increased the number to seven subjects to catch more usability issues of our tested reports [24].

Study Procedure

Every participant tried ten tasks in a safe and private space for an average of 30 minutes per participant. The researchers used a computer laptop to conduct the trial. Windows Media Player software was installed to record the screen while the participants took part in the trial as well as their spoken comments. Task completion time and task completion success were analyzed manually based on the recordings.

The following outcomes were measured:

Performance Metrics

A few metrics were utilized to assess the effectiveness and the efficiency of the tested mapping reports and to uncover usability problems. Some of these metrics are defined in terms of *critical errors*—an error which resulted in an incorrect or incomplete task. If a participant sought help from the test observer to finish a task, it was considered to be a critical error [25]. The investigators measured the following metrics:

1. *Effectiveness: Task Completion Rate (TCR)*. TCR is a measure of tasks that were completed without critical errors, and the outputs of the task were correct [24, 25]. TCR represented the mapping reports' usability effectiveness and was analyzed in two distinct ways: by participant and by task.

- a. *TCR per participant*: The percentage of tasks that were successfully completed by a participant [25].

$$\text{TCR per participant} = \frac{\text{Number of tasks completed successfully}}{\text{Total number of tasks undertaken}} \cdot 100\%$$

- b. *TCR per task*: The percentage of participants who successfully completed a given task [25].

$$\text{TCR per task} = \frac{\text{Number of participants who completed successfully}}{\text{Total number of participants}} \cdot 100\%$$

2. *Efficiency*: The resources expended in relation to the “accuracy and completeness with which users achieve goals” [26]. Using the video records, the time per task was measured from the beginning of the task until the time of start doing of the next task.

The investigators calculated the efficiency and the productivity of the tested mapping reports using the following metrics:

Time Based Efficiency (TBE) per Task. This is a task-specific version of an overall TBE as defined in [20].

$$\bar{p}_{t,j} = \frac{1}{N} \sum_{i=1}^N \frac{n_{ij}}{t_{ij}}$$

Overall Relative Efficiency (ORE) per Task. This is a task-specific version of an overall TBE as defined in [25].

$$\bar{p}_j = \frac{\sum_{i=1}^N n_{ij} t_{ij}}{\sum_{i=1}^N t_{ij}} \cdot 100$$

where

N = Total number of tasks

R = Number of study subjects

n_{ij} = Result of task i by user j

$$= \begin{cases} 1 & \text{if the user successfully completes the task} \\ 0 & \text{otherwise} \end{cases}$$

t_{ij} = The time spent by user j on task i .

User Satisfaction

Overall satisfaction per study subject was measured by the SUS survey. See the details under study design section.

Factors Affecting the Participants' Performance

Before conducting the study, the current study researchers expected that there are some factors that might impact the participants' performance and their satisfaction on the tested maps and we assessed the influence of these elements on the participants' performance. These factors were the participants' education level, work type, experience in healthcare field, and previous experience with mapping reports and GIS tools [27]. The investigators used a variety of statistical methods, as needed, to explore these relationships (Wilcoxon-Mann-Whitney test, Pearson correlation, and simple linear regression). The Wilcoxon-Mann-Whitney test was conducted using the web implementation of the method described in [28]; the remaining analyses were conducted using Excel. The intended sample size of this study was small since we primarily wished to uncover major usability problems; *post-hoc* power calculations for simple linear regression with the observed sample data indicates that the power for testing the relationships between the participants' factors and the TCR or SUS ranged between 3% and 24% [29]. We used a type I error rate (α) of .05 for the hypothesis tests conducted in this project.

Results

1. Participant Demographics

Seven health professionals were interviewed: one white male and six white females. Their ages ranged from the early 30s to late 60s (mean = 49.57 years, median = 49.17 years). Three of the seven participants were from the MPH program and four from the HMI department. Four hold a doctoral degree in a healthcare related field and three have a master's degree in public health or in health management and informatics. Five of the seven participants were working as research or teaching faculty. Two participants were both staff members and doctoral students in the health informatics program, and working in cancer and/or public health research; both had experience in working with mapping reports for at least one year. All seven participants have had experience in healthcare field, ranging from 3 to 38 years (mean = 17.8 years, median = 13 years). The participants' total experience in using mapping interactive reports at work ranged between a few months to 15 years (mean = 5.6 years, median = 2 years). Our participants' work types can be classified, according to their daily work roles, into two broad categories: Faculty and analysts (n = 5), and directors and staff (n = 2).

2. Reports' Effectiveness and Efficiency

The Mapping Reports' Effectiveness

Effectiveness per Participant

A PhD holder participant, who has 13 years of experience in the public health field and in GIS use, could not accomplish two of the assigned tasks because she “had no idea how to navigate them” as she commented. Three of the remaining six participants were not able to follow expected pathways to finish the assigned tasks and got false results for some

tasks. These participants thought that they completed the tasks successfully and did not ask for help or clarification. One of the three participants is a PhD-holding faculty member and the other two are staff members. All three participants had one to six years' experience using GIS tools. Of the remaining three participants, all were able to complete the tasks effectively and efficiently, including one who had the least amount of experience with mapping reports and tools of the seven participants.

The effectiveness was defined as: "The accuracy and completeness with which users achieve specified goals" [26]. The results in our study ranged from 70% to 100%, with only one participant finishing the trial with a TCR < 78% (Figure 1), the minimum score accepted by some scholars [25]. Four of the seven subjects attained a TCR of 90% or more.

Figure 1. Task Completion Rate (TCR) per Participant. [Note: Dark Gold Indicates Participants Who Finished the Trial with $\geq 78\%$ TCR; Red Indicates Participants Who Finished the Trial with $< 78\%$ TCR.]

Effectiveness per Task

The investigators used the task completion formula to measure the TCR by task. The results are shown in Figure 2. Six of the ten assigned tasks reached a TCR of 100% and two of the ten tasks had a TCR of 90% while one task had a TCR of 80% and the remaining task had a TCR of 70%.

Task #s 1, 2, 7, 9, and 10 were very simple, such as open or close a functional button on the reporting map. All had a TCR of 100%.

Tasks #3, 4, 5 & 8, got the lowest TCR, with scores ranging between 70% and 90%.

Before conducting the current study, the study investigators ranked task #s 3, 4, 5, and 8 along with task #6 as complicated tasks that need specific skills and knowledge to be completed successfully. One complicated task, #6, was completed effectively by all subjects.

Figure 2. Task Completion Rate per Task. [Note: Blue Indicates Tasks Involving the Area Health Profile (Tasks 1–6); Red Indicates Tasks Involving the Double Map (Tasks 7–10). Light Blue Indicates Tasks That Had > 78% TCR; Dark Blue Indicates the Task (Task 5) with < 78% TCR.

Mapping Reports' Efficiency and Productivity:

The time per tasks ranges from the minimum two seconds for task #10 to the maximum 297 seconds for task #8 which includes three subtasks. As seen in Table 1, even among the tasks with a 100% completion rate, there was variation in the time spent by the participants. The median time on task #6 was the highest, followed by tasks #8, 5, 4, and 3 respectively and this was relatively related to the complexity of the tasks.

Table 1. Time on Study Tasks

Task #	Task Time Range	Task Time Mean	Task Time Median
1	3-62 seconds	19.4 seconds	12 seconds
2	10-51 seconds	23 seconds	16 seconds
3	13-64 seconds	34.8 seconds	33 seconds
4	20-87 seconds	57 seconds	53 seconds
5	11-268 seconds	95.8 seconds	75 seconds
6	46-215 seconds	136 seconds	145 seconds
7	2-20 seconds	11 seconds	11 seconds
8	90-297 seconds	165.1 seconds	141 seconds
9	3-16 seconds	41.5 seconds	21 seconds

10	2-38 seconds	3.2 seconds	3 seconds
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Time Based Efficiency (TBE) and Overall Relative Efficiency (ORE):

Figures 3 and 4 show the Time Based Efficiency (TBE) and the Overall Relative Efficiency (ORE) for each of the tasks.

Figure 3. Time-based Efficiency (TBE) per Task

Figure 4. Overall Relative Efficiency (ORE) per Task. [Note: Purple Indicates Tasks With 100% ORE per Task; Dark Tan Indicates Task with Less Than 100% ORE per Task]

From Figure 3, we can see that the TBE per task varied for the ten tasks. Task #10 had the highest TBE (19.2 goals/minute); this result conforms to the simplicity of the task (close the map). It is followed by tasks #7, 9 and 1, which are also simple tasks (proceed to the “double map” link on the desktop, open the “area profile” map link in the desktop, and check the sources of our mapping report data, respectively). Tasks #2, 3, and 4 all complicated tasks and had very low TBE rates. Tasks #5, 6, and 8 were the most complicated tasks; they had the lowest TBE levels.

Figure 4 shows that the highest ORE rates were for tasks #1, 2, 9 and 10; they were all simple tasks. Task #6 had about 97% ORE rate despite it being ranked as one of the complicated tasks. Tasks #3, 4, 5, and 8 had the lowest ORE per task.

3. Users' Satisfaction

SUS is a standard ten-question questionnaire given to every participant after the tasks to measure the user satisfaction with the tested maps [20]. The SUS score range for all the participants was 20-100 points with an average of 62.86 points and a median of 50.50 points. The SUS scores for three of the seven study participants were above the target of 68 points and they were satisfied with the maps they tested. The remaining four of our participants' scores were below 68 points. The interpretation of the SUS scores for the study subjects ranged between worst imaginable to best imaginable, and according to the school grade scale, the scores were between A and F with an average of D.

Figure 5. System Usability Scale (SUS) Scores of the Study's Participants. [Note: Brown Color Indicates SUS Score of ≥ 68 Points, and Blue Color Indicates SUS Score of < 68 Points]

4. Factors Affecting the Participants' Performance:

As discussed in the methods section, we expected that there are some factors could impact the participants' performance and their satisfaction on the tested software.

Education Level and Work Type Factors

We assessed whether the education level of the participants impacted the distribution of either their TCR or SUS score using the Wilcoxon-Mann-Whitney test [27]. We classified the participants to PhD and Master Degree holder subjects and we tested these two groups' TCR. We did not find any statistically significant difference in the distribution of the TCR by education level ($P = .91$). Also, there was no statistically significant difference in the distribution of the SUS score by education level ($P = .82$).

The Wilcoxon-Mann-Whitney test was used also to assess whether the participants' distribution of TCR differs by their work type. We categorized the participants into two groups: the faculty and analysts group and the staff and directors group. The difference in the distribution of TCR between the two groups was statistically insignificant ($P = .75$).

Experience in the Healthcare Field and Experience with Mapping Reports and GIS Tools

We conducted simple linear regressions to explore the relationship between the TCR of the study subjects on the usability test and between both the experience in healthcare field and the previous experience with mapping reports and other GIS tools. The relationship between the TCR and the experience in the healthcare field was insignificant ($P = .70$). There was a statistically significant relationship between the subjects' TCRs and experience in GIS tools ($P = .03$). There was no statistically significant relationship

between the SUS levels and the previous experience with healthcare field or with GIS tools for the study participants. The P values for these results was ($P = .82$) and ($P = .17$) respectively.

Table 2 has the results from studying the demographics and experience in the healthcare field and experience with GIS tools versus their TCR and SUS scores of the trials they performed in this study.

Table 2. Demographic and Previous Expertise Factors of the Study Participants Versus the Trial's TCR and the Participants' SUS Scores

The Studied Factors	<i>P</i>
Education Level vs TCR	.91
Education Level vs SUS score	.82
Work Type vs TCR	.75
Previous Experience in Healthcare Field vs TCR	.70
Previous Experience in GIS use vs TCR	.03
Previous Experience in Healthcare Field vs SUS Score	.82
Previous Experience in GIS use vs SUS Score	.17

5. Correlation between the Studied Usability Elements (Effectiveness, Efficiency, And Satisfaction)

As Table 3 shows, we studied the relationship between the TCRs and the SUS scores and this revealed a positive, but statistically insignificant, correlation between the two studied factors ($r = .70$, $P = .08$). The relation between the TCR and both the TBE and the ORE factors were explored. The results revealed that there were positive correlations between the effectiveness (TCR) and both the efficiency in terms of TBE (albeit statistically insignificantly) and ORE (statistically significant) for the studied maps ($r = .50$, $P = .25$ and $r = .92$, $P = <.001$ respectively). There was a positive, but statistically insignificant, correlation between the time spent by the participants for all tasks and the SUS scores they gave after they finished the test. The correlation was positively strong ($r = .70$, $P = .07$).

Table 3. Correlation between the Studied Usability Elements (Effectiveness, efficiency, and Satisfaction)

The Studied Factors	Correlation Coefficient	<i>P</i>
TCR per participant vs SUS Score	.70	.08
TCR per task vs TBE	.50	.25
TCR per task vs ORE	.92	<.001
Efficiency per participant* vs SUS Score	.70	.07

*: The total time in seconds of the whole trial per participant

Discussion

Main Findings

The current study concluded that the tested maps should undergo extensive refining using user-centered approach to overcome the discovered usability issues. This approach could enable map designers to facilitate good user-software interaction and usability. This will let the designers meet their maps' potential users' expectations [30]. Usability testing studies should be conducted before and after releasing the maps to their potential users.

Effectiveness and Efficiency

Effectiveness per Participant

In any usability study, the investigators should always aim for a 100% as a TCR per participant; however, some usability scholars consider a TCR of $\geq 78\%$ per participant acceptable [25]. Six out of the seven participants exceeded the target TCR per participant (78%), and just one participant out of the seven got a rate less than 78% (Figure 1). These results reveal that the trial was carried out effectively by six of the total seven participants. Surprisingly, a PhD holder participant with plenty experience in the public health field and in GIS use could not accomplish two of the assigned tasks while other participants with lower education and null experience handled the trial effectively.

Three participants incorrectly thought that they had effectively completed some tasks because there were no alerts or pop-ups to make them aware that they made mistakes. Some tasks were not dependent on each other, so the participants were not interrupted if the task was wrongly handled. Also, some of these tasks need to be answered by writing on paper and needed specific cognition and knowledge to be answered.

Effectiveness per Task

Our results support the scientific evidence from a study conducted in 2006, which concluded that the technology effectiveness is affected by task complexity factor [31]. Task #s 1, 2, 7, 9, and 10 were very simple, such as open or close a functional button on the reporting map. These tasks did not require that participants find or interpret complicated epidemiologic or statistical results so all the participants were able to complete these tasks successfully.

All the subjects accomplished task #6 effectively although it is categorized among the trial's complicated tasks. This could be due to the study subjects' previous experience in public health and health care, and/or all the subjects were epidemiologists and/or researchers familiar with biostatistics and epidemiology. Additionally, it may be because the task is very connected to the preceding tasks and it was very easy to accomplish when they solved the previous tasks.

Not surprisingly, the remaining complicated tasks, #s 3, 4, 5 and 8, received the lowest TCR scores. Participants who lacked specific skills and knowledge were unable to complete these tasks successfully.

According to the study subjects' comments and by reviewing the recorded trial videos, additional usability issues with the published maps were revealed. These usability problems explained why these tasks were hard to be accomplished even with expert participants in public health, health field, and in GIS tools use. The maps' designer has refined the maps according to comments made by the participants, and we re-released the maps.

Efficiency

From Table 1 we determined that even for the tasks which were ranked easy and non-complicated, some study subjects took more time and effort to get the tasks successfully conducted than the others, and this might need usability adjustment by the tested maps' designer in the future to make these tasks able to be completed by all users within comparable times.

From the TBE results (Figure 3), we expected that in addition to the cognition and knowledge which are needed to accomplish these tasks, the usability issues we discovered in the current study might make these tasks even more complicated than the investigators thought. The ORE results supported previous literature's findings that the efficiency is relatively associated with the complexity of these tasks [31].

After reviewing the recorded videos, the primary investigator concluded that task #6 was easy to handle by the study subjects because it was closely related to its preceding three tasks. The study's audio-video recordings revealed that repeating and re-trying the foregoing tasks allowed task #6's to be accomplishment by all the participants.

Participants' Satisfaction

Based on the SUS scores, we demonstrated that we have to consider our participants comments and refine our tested maps in order to make all our potential users more satisfied and pleased.

We were surprised that many of the SUS scores were very low; this reinforces the need to test systems on potential users rather than assuming that they find the system usable. To improve the user satisfaction, we are willing to consider all the participants' comments to

refine the tested maps. User surveys already were available on the reports to assess the users' satisfaction and collect their feedback on using the mapping reports. The study investigators have acted on doing renovation on the current surveys according to the current study participants' comments, but this remodeling still has not resulted in much feedback so far. All of the mentioned modifications could improve the evaluated reports and might make the polished reports more understandable and usable, and could increase the users' satisfaction [32].

Factors Affecting the Participants' Performance

As the study researchers expected, there was a statistically significant relationship between the subjects' TCRs and their experience in using GIS tools. So, there is dependency of the TCRs on the participants' previous experience with GIS technology. This finding supports the findings of two previous studies revealing that the performance of users on a specific technology are related to previous exposure to that technology [27, 33]. Also, these results supported previous findings of several studies concluding that experience and knowledge affects the task success rates of the tested technology [34, 35].

The investigators did not find any statistically significant relationship between the education level in terms of the graduate degree the participant holds and the participants' TCRs. There was no statistically significant relationship between the participants' education level and their SUS scores. The relationship between the participants' TCRs on the test and their work type was statistically insignificant. The relation between the participants' TCRs and between their experiences in healthcare field was statistically insignificant. The study failed to discover any statistically significant relationship

between the SUS levels and both the TCRs and the previous experience with GIS tools for the study participants.

Correlation between the Studied Usability Elements (Effectiveness, Efficiency, and Satisfaction)

The results revealed strong correlation between the three usability elements. The results support our assumption that the user will be satisfied if they can conduct the trial effectively and efficiently.

Strengths and Limitations of the Study

This is the first usability study to assess published MCR-ARC InstantAtlas™ reports.

This is a good first step; these results might be generalized to assess the usability of all MCR-ARC's mapping reports as well as GIS reports published elsewhere.

The seven participants were all health professionals from academic departments. The small sample size coupled with the use of a non-probability convenience sample of academic health professionals limits the generalizability of these results.

The video records were reviewed manually by one of the investigators. The current study could not capture all the performance and behavior of the participants while they were interacting with the tested maps. A better way to capture participants' awareness and cognitive processes would be to make use of an eye tracking system. The investigators are thinking of using advanced usability software to track user behavior in the future.

Ongoing Work and Recommendations

The investigators conducted a second round of the usability study using professionals who are working directly in day-to-day cancer research and policy after a revision to the

maps based on the findings of this first round. The researchers assumed that second round professionals might have more valuable perspectives and insights towards the tested GIS reports. The investigators conducted the second round study after considering the first round participants' responses and suggestions. All the future MCR-ARC mapping reports' usability should be assessed during the designing process and after publishing the maps. The investigators should use advanced usability tools to test the published maps.

Conclusion

The three main elements of the tested mapping reports' usability were measured and assessed by the current study in terms of: effectiveness, efficiency, and user satisfaction. The tested maps' effectiveness outcomes were better than the efficiency and satisfaction outcomes. The trial was conducted effectively by six of the total seven participants. The study discovered that the effectiveness and efficiency metrics were related to the given tasks' complexity, the easier tasks were accomplished more effectively and efficiently than the complicated tasks. Although most of the study subjects accomplished most of the tasks effectively and efficiently, the users' satisfaction was surprisingly poor.

The current study revealed that there was a statistical significance relationship between the subjects' performance on the study test and the experience in GIS tools.

The study researchers discovered that the pretest questionnaire and the multi-task usability test were not enough to discover all the usability issues of the tested maps. Seeking users' text comments and analyzing the video recordings are very valuable to explore more usability concerns and to reveal the potential users' preferences and perspectives towards GIS tools and maps. The study revealed that in order to facilitate

good map-user interaction and usability, the designers have to conduct usability trials on the maps including the maps potential users before and after publishing them.

The current study results might be generalized to other mapping reports, and might be used to refine the usability and the functionality of these reports as well as other GIS reports and tools of the MCR-ARC. The study findings might point the importance of including the GIS tools' end-users in the basic stages of designing and development of the GIS tools.

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Usability Assessment of the Missouri Cancer Registry's Published Interactive Mapping Reports: Round Two

Abstract

Background: Health-related data's users have trouble understanding and interpreting combined statistical and spatial information. This is the second round of a usability study conducted after we modified and simplified our tested maps based on the first round's results.

Objectives: To explore if the tested maps' usability improved by modifying the maps according to the first round's results

Methods: We recruited 13 cancer professionals from National American Central Cancer registries (NACCR) 2016 conference. The study involved three phases per participant: A pretest questionnaire, the multi-task usability test, and the System Usability Scale (SUS). Software was used to record the computer screen during the trial and the users' spoken comments. We measured several qualitative and quantitative usability metrics. The study's data was analyzed using spreadsheet software.

Results: In the current study, unlike the previous round, there was no significant statistical relationship between the subjects' performance on the study test and the experience in GIS tools ($P = .17$ previously was $.03$). Three out of the four (75%) of our subjects with a bachelor's degree or less accomplished the given tasks effectively and efficiently. This study developed a comparable satisfaction results to the first round study, despite that the previous round's participants were highly educated and more experienced with GIS.

Conclusion: By considering the round one's results and by updating our maps, we made the tested maps simpler to use for subjects who have little experience in using GIS technology, and have little spatial and statistical knowledge.

Keywords: Geographic Information Systems, Interactive Maps, Missouri Cancer Registry, NAACCR, Usability

Introduction

There are enormous Geographic Information System (GIS) technologies that have been created and designed to visualize different kinds of health and health-related data. These tools should be designed and modified to meet the perceptions and needs of these technology's possible users [1]. Software developers and designers, as well as the GIS technology innovators should concentrate on how to make this technology effective and efficient for the targeted users [2, 3].

Public health professionals have started using specific advanced software to examine and illustrate population based databases. Illustrating and visualizing this kind of information becomes essential and important to make a measurable impact on the public health problems in any community. This type of technology has been influential on public health research, as well as on development of new effective public health policy. Therefore, we have to be sure that the population based databases are: Analyzed intelligently and examined appropriately to yield reliable outcomes, and that the results do not mislead the targeted audiences [4].

The previous usability literature pointed out that most of any new numerical technology users face difficulties in interpreting the combined and multiple sources data [5, 6, 7].

The same difficulties have challenged new GIS tools because of the combined geographical and statistical data of these tools. The scientifically proven interpretation was: Insufficient knowledge and inadequate hand-on experience using GIS tools, ignorance and a decline to practice this technology between its prospective users, and because there were usability issues and complexity perception among the possible users towards this kind of technology [8].

As previous scientific research revealed, regular and interactive mapping reports can produce knowledge, create evidence, and augment strategies [9]. Therefore, every interactive mapping report should carry a clear aim and convey a definite message to the targeted audiences [10]. These interactive maps must include citations and details of used information resources and the detailed methodology which followed the production of visualized results. The GIS technology related literature revealed that the mapping reports should undergo strong scrutiny and evaluation, using representative samples of the users, to assess the usability and make this technology fit the users' needs and preferences [4]

The collaboration between public health experts and the other specialists of the same research and practice interests has been proven scientifically and this relation's positive impact on the public health problems and disparities has been confirmed [11]. Using highly advanced and sophisticated GIS tools will help public health experts to plan and create cost-effective, health-related strategies and policies [11]. During the third millennium, the health related maps have changed from being static to be interactive [12]. The scientific literature discovered that the GIS technology users prefer dynamic interactive maps [4]. The same literature concluded that the atlas creators need to take in

their account the potential users' preferences and perceptions. The map developers should consider the users' needs starting from the planning and designing processes, and ending by evaluating the maps before and after releasing them to the actual users [13].

In the first round of the study, the investigators conducted a usability testing trial to assess the usability of the two published Missouri Cancer Registry and Research Center (MCR-ARC)'s interactive reports. The first round's participants were faculty and staff of Master of Public Health program (MPH) and the Department of Health Management and Informatics (HMI) at University of Missouri-Columbia.

In the current study, we conducted a second round of the same first round's methodology to measure effectiveness and efficiency of the published InstantAtlas™ reports of MCR-ARC. In this round, we selected a convenience sample of cancer professionals who attended the North America Association of Central Cancer Registries (NAACCR) conference-June, 2016. The current study investigators refined MCR-ARC's published mapping reports based on the first round study's results trying to meet the satisfaction of their professional end-users. The second round of study also aims to evaluate if and to what extent the users' action will be influenced by the users' demographic information, experience, education level, and the work type.

Methods

Study Design

The investigators selected a mixed methodology tactic. The tested mapping reports are already published on the MCR-ARC website as: An Area Profile and a Double Map including cancer, behavioral, and demographic indicators on Missouri counties level (see

Multimedia Appendices 1 and 2) [14, 15]. The trial elements were the same Round One's components: A pretest questionnaire, the multi-task usability test, and the System Usability Scale (SUS) per every participant respectively [16].

The Pretest Questionnaire

The questionnaire involved inquiries on every subject's age, race, work type, education level, total experience in public health field, and experience in GIS tools use (see Multimedia Appendix 3).

Multi-task Usability Test

This stage included ten independently ranked tasks, which were applied on the tested maps. These tasks were handled by the study subjects individually to test the usability of the tested InstantAtlas™ reports. The multi-task scenario was constructed by the study's investigators grounded on the anticipated functionality of the tested maps. This phase aimed to precisely estimate the efficiency and effectiveness in terms of task completion success rate and task completion time [17]. All the tasks were in the same classification and context for all subjects (see Multimedia Appendix 3).

The System Usability Scale (SUS)

This phase was composed of a manufacturing and simple ten-item scale to assess the subjects' independent assessment of the experienced mapping reports' usability. This phase was immediately conducted after the multi-task scenario phase. The SUS score range is between 0 and 100. Sixty-eight or above has been considered as satisfactory based on previous usability literature and upper score up to 100 is the optimum to finest

score [16]. Scores above 68 points are acceptable according to usability scholars and higher scores represent the optimal to best score [16].

Participants

The current study's primary investigator attended the NAACCR-2016 conference and she convinced group of attendees to participate in the study and conduct the study's trial. The convenience sampling method was selected to collect the current study's participants. The investigators conducted the study's experiment on the first reacted thirteen participants. As the usability scholars confirmed, five was the smallest number of subjects to run a fruitful usability study; a five subjects study enables revealing from 55 to 100% of the usability issues of any experienced material [18]. The investigators increased the number to thirteen subjects to expose as many as probable of the usability issues of our refined published mapping reports [19, 20].

Study Procedure

A specific computer laptop was used to conduct the study. The researchers installed a Microsoft Windows-7 software, Windows Media Player, to audio-video record the laptop's screen while the subjects performing the experiment. Every subject conducted the study trial in a secure and private area for an average of 30 minutes per subject. Task on time and task completion success rate were analyzed manually by the primary investigator based on the experiment's audio-video laptop screen records.

The subsequent usability metrics were also measured:

Performance Metrics

These measures are the finest metrics to evaluate the effectiveness and the efficiency and to reveal the usability issues of the experienced interactive mapping reports. There are some definitions used in the current study to make the results and the measures more explainable: *The critical error* is the error which will result in an incorrect or incomplete task. If the participant will consider seeking help from the test observer to finish any of the trial's tasks, we will consider that as a critical error [21]. *The non-critical error* is the error will have influence on the final output of the task and impacts the task's efficiency [21]. The investigators measured the following metrics:

1. *Effectiveness, Task Completion Rate (TCR)*: According to ISO-9241, the usability experts defined the usability effectiveness as: “The accuracy and completeness with which users achieve specified goals” [22].

- a. *TCR per participant*: The percentage of tasks that were successfully completed by a participant [21].

$$\text{TCR per participant} = \frac{\text{Number of tasks completed successfully}}{\text{Total number of tasks undertaken}} \cdot 100\%$$

- b. *TCR per task*: The percentage of participants who successfully completed a given task [21].

$$\text{TCR per task} = \frac{\text{Number of participants who completed successfully}}{\text{Total number of participants}} \cdot 100\%$$

2. *Efficiency*: The efficiency is defined according to the ISO-9241 as:

“Resources spent by user in order to ensure accurate and complete

achievement of the goals” [22]. The investigators calculated the efficiency and the productivity of the tested mapping reports using the following couple of formulas

a. *Time Based Efficiency (TBE)* [21]

$$\bar{P}_{t,j} = \frac{1}{N} \sum_{i=1}^N \frac{n_{ij}}{t_{ij}}$$

b. *Overall Relative Efficiency (ORE)* [21]

$$\bar{P}_j = \frac{\sum_{i=1}^N n_{ij} t_{ij}}{\sum_{i=1}^N t_{ij}} \cdot 100$$

N = Total number of tasks

R = Number of study subjects

n_{ij} = Result of task i by user j ; n_{ij}

$$= \begin{cases} 1 & \text{if the user successfully completes the task} \\ 0 & \text{otherwise} \end{cases}$$

t_{ij} = The time spent by user j on task i .

User Satisfaction

SUS scale was used to assess the satisfaction per study subject. See the detailed SUS mechanism under the study design section.

Factors Affecting the Participants' Performance

The current study researchers measured some factors that they expected might impact the participants' performance and satisfaction during the trial. Those factors were: the

participants' education level, work type, experience in healthcare field, and previous experience with mapping reports and GIS tools. The investigators chose different statistical measures, as needed, to assess the chosen factors' relationships (Wilcoxon-Mann-Whitney test calculator [23], Pearson correlation test, and/or simple regression test). Although the study sample is small, we could have some estimates using the simple linear regression test to measure some of the study's results. The study data analyzed using Excel spreadsheets and we used a type I error rate (α) of 0.05 for the hypothesis tests conducted in this project.

Results

1. Participant Demographics

The study researchers interviewed thirteen cancer health professionals, four males and nine females. Their ages ranged from 29-56 years old (Mean=40.85 years old, Median=40 years old). All of the thirteen participants were cancer professionals who attended NAACCR-2016 conference. The race of our participants was varied: seven Whites, four African-Americans, one Asian, and one Native Hawaiian or other Pacific Islander. Three of the subjects hold PhD degrees, six hold master degrees, one bachelor holder, one associate degree holder, and only one got some college level education. The associate degree and the some college holders were working as certified cancer registrars in two separate central cancer registries. At the time of data collection, the PhD holder subjects' work roles were: a cancer researcher, an epidemiologist, and a director and associate professor. The master degree holders' work roles were: a program director and epidemiologist, a statistical consultant, a research coordinator, a software engineer, a cancer surveillance and epidemiologist, and an epidemiologist. The bachelor degree

holders were functioning as: a research analyst and public health epidemiologist, and an abstractor and quality control manager. The associate degree holder was functioning as a certified cancer registrar and the subject who holds some college education was working as a data manager in a central cancer registry. The total experience in public health for the all subjects ranged between 2 years to 19 years (Average= 10.38 years, Median= 10 years). The subjects' total experience in using GIS tools in work was between null experience to 10 years (Mean= 2 years, Median= 0 years).

2. Reports' Effectiveness and Efficiency

The Mapping Reports' Effectiveness

Effectiveness per Participant

One of the participants could not complete three successive tasks #4, 5, & 6. The subject held a bachelor degree and she did not have any previous experience in using GIS tools and interactive mapping reports. Another subject could not get the assigned results for two successive tasks #4 & 5. This subject holds a PhD degree and has had experience in public health for 15 years, experience in using GIS tools at work, and work as a director at one of the central cancer registries. Two of the subjects could not complete two non-successive tasks: one of these subjects holds master's degree and could not finish the tasks #5 & 8 successfully and another subject holds just some college education missed the tasks #4 & 8. The master's degree subject had experience in public health field for 15 years and five years of using GIS tools and software, and the some college degree holder had experience of 19 years in public health and no previous experience in using or reading GIS tools. Four of our subjects could not accomplish just one task and the missed tasks were #5, 6, & 9. Two of these participants were PhD holders, one master degree

holder, and a bachelor degree holder. The two PhD holders had experience of 8 and 10 years in public health field and experience of 4 and 5 years of using GIS tools in their daily work. The master degree holder had 17 years of public health experience and no previous experience in GIS tools. The bachelor degree holder had experience in public health field of 10 years with null experience in using GIS tools.

Only four of our 13 participants (30.76%) achieved the TCR of 100%. Three of these participants were master's degree holders and one of them held an associate degree in science. These four subjects have experience in public health field between two to ten years, and all of them carried no previous experience in using GIS tools and interactive mapping reports. Twelve of our 13 participants (92.30%) were able to accomplish the tasks with TCR of 79% or above. The only one subject who got TCR of <79% was a PhD holder and a director of a central cancer registry with 12 years public health experience and null GIS experience.

The results were ranged from 70% to 100% as Figure (1) shows.

Figure 1. Task Completion Rate for All Tasks per Participant. [Note: Blue Bars Indicates Participants Who Finished the Trial with $\geq 78\%$ TCR; Purple Bar Indicates Participants Who Finished the Trial with $<78\%$ TCR.]

Effectiveness per Single Task

The above task completion formula was also used to calculate the task completion rate per task of the study's ten tasks. The results are presented in Figure (2)

Figure 2. Task Completion Rate per Task for All Participants. [Note: Blue Indicates Tasks Involving the Area Health Profile (Tasks 1–6); Red Indicates Tasks Involving the Double Map (Tasks 7–10)]

As Figure (2) shows, four tasks (38.46%) reached the 100% completion success rate, one task (7.69%) got 90% of the completion success rate, one task (7.69%) got 85% or higher completion rate and three tasks (23.08%) got less than 80% of completion success rate.

The tasks #1, 2, 3, 7, and 10 got TCR of 100%. As the multi-task scenario shows (see the appendix), the tasks #1, 2, & 10 had very simple context and functionality. The

mentioned tasks do not need to explain or interpret difficult epidemiology or statistical outcomes. Task # 3 was ranked as a one of the complicated tasks but it was successfully accomplished by all the subjects.

Task #6 was ranked as one of the complicated tasks, but was accomplished effectively in both study rounds. Task #6 was effectively accomplished by the study subjects in the two rounds of the study, with completion rate of 100% in the first round and just 85% in the second round.

The tasks #4, 5 & 8 had the lowermost TCRs. These tasks were not effectively conducted because the tasks' TCRs were less than 78%. These tasks were ranked as difficult tasks and require certain abilities and understanding to be completed successfully. Some of these tasks are multi-stepping tasks and needs special knowledge to be figured out. From the first round of the study, the same tasks in addition to the task # 3 got the lowest completion rates.

Mapping Reports' Efficiency and Productivity

The investigators used the audio-video records to measure the time per task which was measured from starting the examined task to the time of beginning the next task. The median of task #8 was the highest followed by # 4, 5, 6, and 3. This was relatively connected to the task's difficulty. Table (1) shows the times which our subjects spent on the study tasks individually.

Table 1. Time on the Study Tasks

Task #	Task Time Range	Task Time Mean	Task Time Median
1	6-17 seconds	9.77 seconds	7 seconds
2	6-300 seconds	44.92 seconds	16 seconds
3	6-114 seconds	28.69 seconds	19 seconds
4	9-166 seconds	83.38 seconds	113 seconds
5	12-245 seconds	85 seconds	51 seconds
6	15-196 seconds	82.62 seconds	78 seconds
7	6-43 seconds	11.62 seconds	8 seconds
8	50-429 seconds	182.77 seconds	179 seconds
9	9-26 seconds	13.75 seconds	12 seconds
10	3-7 seconds	5.54 seconds	6 seconds

Time Based Efficiency and Overall Relative Efficiency

The time based efficiency rates were ranged between 0 goals/second for task #8 and 0.12 goals/second for task #1. Figures (3) and (4) show the time based efficiency and the overall relative efficiency for every individual performed tasks.

Figure 3. Time-based Efficiency (TBE) per Task

From Figure (3), the TBE per task was different for the all the tasks. Task #10 gained the maximum TBE (.35 Goals/Second) and this result was associated with ease of the task (close the map), followed by the tasks #7, 9 and 1 and all of them ranked as simple and straight forward tasks (proceed to the “double map” link on the desktop, open the “area profile” map link in the desktop, and check the sources of our mapping report data). Tasks #5, 6, and 8 got the lowest TBE levels, 0 goals/second for the task #8 and .02 goals/second for the tasks # 5 & 6. Tasks #5, 6, &8 were ranked as the most complicated tasks.

Figure 4. Overall Relative Efficiency per Task. [Note: Orange Indicates Tasks with 100% ORE per Task; Dark Tan Indicates Task with Less Than 100% ORE per Task]

Figure (4) shows that the highest ORE rates were for the tasks #1, 2, 3, 9 & 10 and they were categorized as easy tasks except the task #3, which is ranked as a complex task.

Task #8 got an OTE of 93% in comparison to almost OTE of 90% in the first round. Task #6, a ranked complicated task, followed with an OTE of 88% ORE rate, in comparison to the OTE of about 95% in the first round. Tasks # 4, 5, & 7 had the lowest ORE per task.

3. Users' Satisfaction

The scale was given to every study subject to be completed at the end of the study experiment. This tool was constructed to assess expectations and insights of the users regarding the tested systems [16]. Figure 5 presents the study subjects' SUS scores.

Figure 5. System Usability Scale (SUS) Scores of the Study's Participants. [Note: Brown Color Indicates SUS Score of ≥ 68 Points; Blue Color Indicates SUS Score of < 68 Points]

SUS scores can be between 0 and 100. As Figure 5 illustrates, the SUS scores for the current study's subjects ranged from 25 to 82.5, with a mean of 58.85 points and median of 65 points. Four of our 13 (30.77%) participants had a SUS score of more than 68 points; the remaining nine subjects (69.23%) did not reach the accepted satisfaction point.

4. Factors Affect the Participants' Performance

Education Level and Work Type Factors

The researchers conducted Wilcoxon-Mann-Whitney test to explore the statistical association among the education level of the participants from one part and the task completion rate and the SUS scale for the study subjects. There was no significant statistical difference between the performance of the graduate school degrees holder participants and the undergraduate degree or less holder participants ($P = .51$). The

results show that there was no significant statistical relationship between the participants' education level and the satisfaction score of the SUS ($P = .16$).

The same inferential test was also used to assess the statistical relationship between the participants' performance on the test in terms of the task completion rate and the work type of the same participants as cancer researchers and epidemiologists from one part, and participants who do not do research and do not have previous experience in cancer epidemiology or surveillance on the other part. The relationship between the studied two factors was statistically insignificant ($P = .41$).

Experience in Healthcare Field and Experience with Mapping Reports and GIS Tools Factors

A simple regression test was used to search if there is a significant statistical relationship between the performances of the study participants in the current usability trial and between both: the experience in healthcare field and the previous experience with mapping reports and other GIS tools. The statistical relation between the performances of the participants in the trial and between the experience in healthcare field was insignificant ($P = .51$). In the current study, there was no significant statistical relationship between the subjects' performance on the study test and the experience in GIS tools ($P = .17$).

After we conducted a simple linear regression test, there was no significant statistical relationship between the SUS levels and both the experiment completion rate and the previous experience with GIS tools for the study participants. The P values for these results were ($P = .67$) and ($P = .61$) respectively.

Table 2. Demographic and Previous Expertise Factors of the Study Participants Versus the Trial's TCR and the Participants' SUS Scores

The Studied Factors	<i>P</i>
Education Level Per participant vs TCR Per Participant	.51
Education Level per Participant vs SUS Score Per Participant	.16
Work Type Per Participant vs TCR Per Participant	.41
Previous Experience in Healthcare Field Per Participant vs TCR Per participant	.51
Previous Experience in GIS Use Per Participant vs TCR Per Participant	.17
Previous Experience in GIS Use Per Participant vs SUS Score Per Participant	.61

5. Correlation between the Studied Usability Elements (Effectiveness, Efficiency, and Satisfaction)

We measured the correlation between the major three usability elements, effectiveness, efficiency, and the satisfaction of the users. The current study revealed the following findings:

There was a very weak correlation between the task completion rates and the SUS scores for the participants ($r = .31$, $P = .31$), while the correlation was very high between these factors in the first round of the study ($r = .7$, $P = .08$).

The researchers studied the relation between the task completion rates by task from one side and both the TBE and the ORE factors. The current study discovered that there were strong correlation between the effectiveness and the efficiency usability elements of the studied maps and the correlation was: ($r = .39$, $P = .18$) and ($r = .81$, $P = <.001$). The correlation is weaker than the correlation between these factors in the first round of the study ($r = .50$, $P = .25$), and ($r = .92$, $P = .003$).

The current research also discovered a very strong correlation between the time spent by the participants on the given tasks and the study subjects' satisfaction ($r = .92$, $P = <.001$). This correlation is stronger than the correlation between the same factors in the first round of the study ($r = .70$, $P = 0.07$).

Table 3. Correlation between the Studied Usability Elements (Effectiveness, efficiency, and Satisfaction)

The Studied Factors	Correlation Coefficient	P-Value
TCR vs SUS Score	.31	.31
TCR vs TBE	.39	.18
TCR vs ORE	.81	<.001
Total Time Of The Trial (Efficiency) Per Participant vs SUS Score	.92	<.001

Discussion

Main Findings

The current study was a second round of a usability testing study was conducted to assess usability of the published mapping report of MCR-ARC. This multi-approach usability testing methods might aid map creators to design user-friendly mapping reports and help them to access the maps' prospective users' anticipations. The study findings support using usability testing studies before and after releasing the MCR-ARC maps to the potential users.

Participant Demographics

The researchers conducted this study as a second round of the previous pilot usability study on the same tested mapping reports which are published by MCR-ARC. Previous study includes seven convenient academic health professionals. The investigators refined the tested maps and the usability study's multi-tasks scenario considering all the recommendations and preferences from the first round subjects. The investigators assumed that the first round's results might be tightly connected to the favorites and the insights of the academic health professionals who did not handle cancer data registration and/or analysis, did not directly make and advocate for cancer policy, and did not use cancer mapping reports in their daily practical life. That is why the investigators tried to apply the experiment on the cancer officials who were attending NAACCR-2016 conference aiming to explore the usability of the refined tested maps using a convenience sample of cancer officials.

Effectiveness and Efficiency

Effectiveness per Participant

In the current study, we are aiming to attain 100% of completion success rate per participant, but the usability specialists allocated that for any usability study it is ok to consider 78% as the average TCR per participant [21].

According to the results in Figure (1), the trial was completed effectively by twelve out of our 13 participants (92.30%). The trial was conducted effectively despite the diversity in the education, public health field experience, or GIS experience of the study subjects. A PhD holder subject with a heavy cancer and public field experience could not accomplish the minimum border of the accepted TCR, while the other lower educated and less experienced subjects could handle the test effectively.

Effectiveness per Task

As the results section shows, the ranked easy tasks were accomplished more effectively than the tasks ranked as complicated. These findings supported the first round study and a previous scientific article's results, which revealed that tasks accomplishments are influenced by the task context's complexity [24].

Surprisingly, task #6 was graded as one of the complex tasks but was conducted successfully in both study rounds. In this study round, it could be explained that because the task is very linked to the prior tasks and it was easy to handle after the subject solve the former tasks. The variance in TCRs per task between the two rounds of study might be interpreted as following: The second round's participants' educational backgrounds were very diverse and not all of them had solid epidemiological and/or statistical background that the first round participants hold.

Efficiency

As in the first round of the study, there was difference in the time per task even with the TCR of 100%. The study subjects in the two study rounds spent various time to accomplish the given tasks. As we revealed from the first round of the study, these findings were relatively related to the complexity of the tasks, where the complex tasks took longer than the easy tasks.

Also as we revealed from the first round, this round of study discovered that even the simply ranked tasks, some of the subjects consumed longer time to accomplish the tasks effectively than the other subjects. These results are unpredictable because, as we discussed previously, the study investigators adjusted the tested maps according to the first round subjects' comments. Based on the TBE results from the previous study round and the current one, the investigators expected that in addition to the intellect and knowledge which are essential to achieve these tasks. The usability problems also could even make the given tasks more difficult than the study researchers assumed before they started the study. For both study rounds, we revealed that OTEs for most tasks were fairly related to the difficulty of these tasks' context, and this supports the previous usability literature findings [22]. But surprisingly, this is inapplicable for the previously ranked complicated tasks, #3, 6 & 8. After close scrutiny of the recordings, we discovered that the repeatability and re-doing of the preceding tasks profoundly influenced the tasks #3, 6 and 8 completions by the study subjects in both study rounds.

Participant's Satisfaction

Sixty eight points or more has been considered satisfactory according to usability literature and advanced marks through 100 points exemplify the optimal to greatest SUS

score. In comparison to the first round of the study, we found that both rounds have an average and the medians measures of less than 68 points and were close to each other.

Our explanation to the comparability of the satisfaction results between both study rounds is that in the second round, we tested cancer professionals of more varied races and with mixed graduate and undergraduate levels and most of these participants had null previous experience in using GIS. These participants developed a comparable satisfaction results as the first round study's subjects, who were holding graduate degrees and had rich experience in statistical and epidemiological knowledge, as well as previous experience in using GIS tools. We assumed that, when we updated our maps according to the first round's results, we simplified our tested maps to fit the needs of our potential users of different biographic and experience levels.

Usability scholars revealed that the users' insights and anticipations are critical to building faultless technology. Considering all the users' commentaries are essential to make the technology more satisfactory and useful [24]. We considered the participants' texts which were taken at the end of every trial, in addition to the audio-visual records of all the participants to explore more usability issues of the tested maps. The revealed usability issues helped us to explain and find out why some of the assigned study tasks were hard to be handled by the highly educated and knowledgeable subjects. The study researchers considered all of the discovered usability problems, and accordingly, will refine our published mapping reports and publicize them on the registry's website.

Factors Affect the Participants' Performance

There weren't significant statistical relationships between all the studied factors. While there was a significant statistical relationship between TCR rates and the previous experience in using GIS tools in the first round of the study, in this round, there is no significant statistical relationship between these two factors. The current study's finding might be explained as following: By considering the round one's results and by updating our maps, we made the tested maps simpler to be used by the subjects who had null experience in using GIS technology. Both study rounds revealed that there is no dependency of the SUS score on the both the TCR and the previous experience with GIS tools for the study participants as the investigators assumed.

The Correlation between the Studied Usability Elements (Effectiveness, Efficiency, and Satisfaction)

The results revealed positive correlation between the three usability elements which range from very weak to very strong positive correlations. The strong correlation between the SUS and the efficiency is very reasonable, and this supports the findings of the previous round. This could be explained that by updating the maps, we made the maps more usable by the users, and the participants conducted the trial more efficiently and they were satisfied about the entire experience.

Strength and Limitation of the Study

This study is the second round of the usability research conducted on the published MCR-ARC InstantAtlas™ mapping reports to evaluate the quantitative and qualitative measurements using a larger sample than we used for the first round. The investigators used a sample of 13 participants who are professionals in cancer epidemiology, cancer

surveillance and/or cancer research. We are assuming that the second round professional participants will be the potential users of the interactive mapping reports rather than the academia people who had been selected for the first round trial. Larger sample of cancer professionals and testing the modified reports based on the first round's findings, make this round more reasonable and the results tend to be more applicable. These results might be generalized to assess the usability and the functionality of all the MCR-ARC's mapping reports.

There are several limitations for the study. The sampling technique was the convenience sampling method. The methodology might not determine all the detailed performance and behavioral usability metrics of the participants. The audio-video records were analyzed manually by the primary investigator. We might also think of introducing more sophisticated methodology using advanced usability software, for example, advanced usability software and/or Eye Tracking software to record and analyze our usability data.

Future Directions and Recommendations

We are recommending conducting usability testing pilots on all current and the future designed mapping reports by the MCR-ARC. Also, we are targeting that usability assessment should begin from the planning procedure, map release, and after dissemination the mapping reports by using a representative sample of these maps' probable users to precisely assess the usability of these maps. Additionally, we are hoping that we could use more advanced usability tools in future to evaluate our released maps.

Conclusion

Current round of the study measured the three main components of the refined tested mapping reports: effectiveness, efficiency, and user satisfaction. The study results supported the first round's findings that the three usability elements are correlated positively to each other. As we revealed from the previous round, the examined reports' effectiveness results were superior in comparison to the efficiency and satisfaction results. As we pointed out from the first round, we revealed that the effectiveness and efficiency metrics were strongly associated with the trial tasks context's complexity. As we concluded in the previous study, the graded simple tasks were achieved more effectively and more efficiently than the graded complicated tasks. The SUS scores of the current study round were comparable to the previous round study's SUS scores with a poor average and median while the SUS score ranges of the both studies were ranged from very poor to excellent scores.

The current study, as opposed to the previous round, showed that there was no significant statistical relationship between the subjects' performance on the study test and having previous experience in using the GIS tools. We explained this finding that, by updating the tested maps and tasks, we made the reports simpler to be used even by users who do not have previous GIS experience. As we learned from the previous round of the study, the researchers did not reveal any significant statistical relationship between all the studied factors.

As we concluded previously from the first round, we learned that the pretest questionnaire and the multitask scenario are not enough to reveal all the usability problems of the examined mapping reports. Also, we concluded that pursuing users' text

remarks closely investigating the audio-video records are very treasured in discovering more usability issues and exploring the users' favorites and perceptions towards GIS technology.

We concluded that the examined mapping reports must be extensively refined and modified to correct all the revealed usability concerns and to meet the perceptions and requirements of the maps' potential users.

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APPENDICIES

Appendix A: Creation of the Senate District Population File (2008-2012)

For the fourteen (14) districts that are aggregations of counties, the district population is simply the aggregation of the age, race, year, and sex populations of the corresponding counties. For the remaining twenty (20) districts with boundaries that do not follow county boundaries, the population file was constructed with the following process:

1. A set of twenty (20) senate district groupings we termed “senate district grouped to county boundaries” (SDGCs) were created that minimally aggregated the districts to follow county boundaries. The 20 SDGCs are each of the 14 districts that originally followed county boundaries along with the following six (6) aggregated regions: 8 districts of Franklin County, St. Louis City, and St. Louis County; 2 districts of St. Charles County; 2 districts covering 6 counties south of St. Louis; 4 districts of Jackson County; 2 districts covering 15 counties in northwest Missouri; and 2 districts covering Christian and Greene counties).
2. The county-level population file obtained via the SEER program was aggregated in to the 20 SDGCs created in step 1 for each of the age (19 groups), bridged single-race, year, and sex groupings.
3. Non-annual, but senate district level, population counts by age, race, and sex were created by the following steps:
 - a. The following senate-district-level, sex-by-age, 2009-2013 Census American Community (ACS) tables were downloaded: B01001 (all races combined) and B01001A-B01001E (white alone, African-American alone, American Indian/ American Native) AI/AN alone, Asian alone, Native Hawaiian or Other Pacific Islander (NH/OPI) alone.
 - b. The all races combined ACS populations (which were mostly in 5-year groupings except for extra breaks in the late teens/early twenties and

- retirement age, and all ages over 85 were grouped) were aggregated into 18 groups of 5-years with 85+.
- c. The race-specific ACS populations (which had 5-year groupings under age 35 except with a break age at 18, 10-year groupings over the age 35, and all ages over 85 were grouped) were aggregated into 13 groups by collapsing the break at age 18.
 - d. Separately for each sex, race-specific populations in 18 groups were estimated by splitting the 10-year spans in the ACS race-specific population into the two 5-year spans by allocating the population proportional to the all races combined ACS population.
 - e. The Asian alone and NH/OPI alone 18 age-group populations were added together to create an Asian/Pacific Islander (A/PI) population file.
4. For each sex and the 4 races (white alone, African-American alone, AI/AN alone, and A/PI), the 18 age-group senate-district-level populations were aggregated into the 20 SDGCs created in step 1.
 5. Proportions allocating SGD populations to senate districts were computed with the following steps:
 - a. For each age (18 groups), race (4 groups), sex, and SDGC combination: the proportion of the population within each of the contained senate district was computed.
 - b. Population proportions in 19 groups were approximated by letting both the proportions for <1 year-olds and the proportions of 1-4 year-olds be equal to the proportions of 0-4 year-olds for each race, sex, and SDGC combination.
 6. Finally, the proportions computed in step 5 were applied to the SEER population file aggregated in step 2 to allocate the SDGC populations to each contained

senate district by age (19 groups), race, year, and sex. Here, the bridged single-race groupings of the SEER population file were approximated with the race-alone groupings originating from the ACS population files.

*Hispanic ethnicity was not considered during the construction of this population file.

Appendix B: Usability Testing Questionnaire

Pre-Trial Questionnaire

Participant #

Age:

Gender: Female Male Other

Race:

American Indian or Alaskan Native

Asian

African-American

Native Hawaiian or Other Pacific Islander

White

Other

Education level:

.....

Employment role (work type):

.....

Institution name:

.....

Total experience in public health field:

.....

.....

Total experience in using GIS interactive reports in work:

.....

.....

.....

Appendix C: Multi-task Test Scenario

Multi-task Usability Testing

Task (1):

Open the “**Area Health Profile**” link on the desktop

Task (2):

Open “Choose Map Data”

Task (3):

Choose the age-adjusted incidence rates for Female Breast 55+ for 2008-2012

Task (4):

Write down the incidence rate and the 95% confidence interval (CI) for Boone
County

Rate:	Confidence Interval
(CI).....	

Task (5):

Was the rate statistically significantly higher, lower, or no different from the
statewide rate?

.....

Task (6):

What is the bar graph on the right side representing?

.....

...

.....

...

Task (7):

Proceed to the “**Double Map**” link on the desktop

Task (8):

Subtask I:

Choose the age-adjusted incidence rates for Female Breast 40+ indicator for 2003-2012 as indicator 1

Subtask II:

Choose Age adjusted incidence for Lung and bronchus indicator for 2003-2012 as indicator 2

Subtask III:

Write down the correlation coefficient and the regression equation

Correlation coefficient:

Regression equation:

Task (9):

Check the sources of our mapping report data

Task (10):

Close the map

Appendix D: SUS Scale for Testing MCR-ARC Mapping Reports

System Usability Scale

© Digital Equipment Corporation, 1986.

	Strongly disagree						Strongly agree
1. I think that I would like to use this interactive mapping report frequently	☐	☐	☐	☐	☐		
	1	2	3	4	5		
2. I found the mapping report unnecessarily complex	☐	☐	☐	☐	☐		
	1	2	3	4	5		
3. I thought the mapping report was easy to use	☐	☐	☐	☐	☐		
	1	2	3	4	5		
4. I think that I would need the support of a technical person to be able to use this mapping report	☐	☐	☐	☐	☐		
	1	2	3	4	5		
5. I found the various functions in this mapping report were well integrated	☐	☐	☐	☐	☐		
	1	2	3	4	5		
6. I thought there was too much inconsistency in this mapping report	☐	☐	☐	☐	☐		
	1	2	3	4	5		
7. I would imagine that most people would learn to use this mapping report very quickly	☐	☐	☐	☐	☐		
	1	2	3	4	5		
8. I found the mapping report very cumbersome to use	☐	☐	☐	☐	☐		
	1	2	3	4	5		
9. I felt very confident using the mapping report	☐	☐	☐	☐	☐		
	1	2	3	4	5		
10. I needed to learn a lot of things before I could get going with this mapping report	☐	☐	☐	☐	☐		
	1	2	3	4	5		

Appendix E: Usability Trial's Recruitment Email

Invitation to Participate in a Usability Testing Study

Dear Health Professional;

We are asking you to participate in a research study that is IRB approved. This study will investigate the usability of the published interactive mapping reports of the Missouri Cancer Registry and Research Center MCR-ARC.

If you chose to participate, the Principal Investigator (PI) will interview you. The testing session will last about 20 minutes and your face and other body parts will not be recorded.

How do I sign up?

Simply send an email to the following email address (aab365@mail.missouri.edu), and we will set up a 20 minutes appointment. The PI, Awatef Ben Ramadan, will handle it from there. We will arrange to meet you in a private and confident space to conduct the trial during the conference period.

The study investigators:

1. Awatef Ahmed Ben Ramadan, MD, MPH

Graduate Research Assistant at MCR-ARC and HMI Department

2. Jeannette Jackson-Thompson, MSPH, PhD

Director, Missouri Cancer Registry and Research Center

Research Associate Professor, Health Management & Informatics

University of Missouri School of Medicine

3. *Chester Lee Schmaltz, PhD*

Senior Statistician, Missouri Cancer Registry and Research Center

Teaching Professor, Department of Health Management and Informatics

University of Missouri School of Medicine

Please do not hesitate to contact us on aab365@mail.missouri.edu or call me at

*(573) ***_*****

Thank you very much

Awatef Ahmed Ben Ramadan, MD, MPH

PhD Student - University Missouri Informatics

Institute (MUII)

GRA at Missouri Cancer Registry (MCR-ARC)

University of Missouri, Columbia

aab365@mail.missouri.edu

VITA

I am a MD, MPH, & a PhD in Health Informatics from University of Missouri Informatics Institute (MUII). I am graduating on December 15th, 2017. I worked as a physician and a supervisor of immunization program in a community health center, researcher and lecturer at the Family and Community Medicine Department from 2003-2008, and worked as a graduate research assistant at the Missouri Cancer Registry and Research Center at the University of Missouri for the period from 2014 to 2017. Presented several posters and oral presentation in many peer-reviewed national and international conferences. Published total seven articles and submitted other three manuscripts for well-respected informatics journals. I have a rich experience in working on SPSS and SAS software. I am skilled in writing research grants in R01, R03, and R21 formats.