Interactive Dashboards: Using Visual Analytics for knowledge Transfer and Decision Support

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ABSTRACT

With the advancement in information technologies, complex and multidimensional data are generated at an unprecedented rate. The public health sector is challenged with complex and dynamic health data that are produced and housed in health information systems. These data impose a challenge on data analysts and decision makers to understand and make informed decisions about 'wicked' health problems. This study synthesizes the Delphi method approach and the Visual Analytics methodology to solicit experts' inputs and focus their skills and expertise to inform the design of a visual analytical tool that can be employed to help health professionals to understand complex and heterogeneous health data, build knowledge and make informed decisions. This study introduced the design of an Analytic Injury Dashboard (AID) to help health professionals monitor and understand health indicators to make informed decisions and initiate appropriate actions. Furthermore, this study presents an empirical evaluation of the AID dashboard in a collaborative setting with multiple health stakeholders using real domain health data. Findings generated from this study will help to inform the design of effective visualization dashboard that can be used as a decision-support tool within the public health sector.

Keywords: Visual Analytics, Public Health, Group Analytics, Problem Solving, Decision-Making.

Index Terms: H.5.2 [User Interface]: User-Centered Design; I.3.6 [Methodology and Techniques]: Interaction Techniques; K:4:3 [Organizational Impacts]: Computer Supported Collaborative Work.

1 INTRODUCTION

With the advancement in information technologies, complex and multidimensional data are generated at an unprecedented rate. In this data rich world, from intelligence to finance to healthcare, multidimensional and dynamic datasets impose a challenge on data analysts and decision makers to understand and make informed decisions about complex events and situations. When dealing with dynamic problems characterized by uncertain data that follow unknown trends and patterns, computational and mathematical analytics and logic modelling fail to effectively model the data and solve the analytical problem at hand. Dynamic and 'ill structured' problems combine multidimensional elements to constitute what Kirschner et al. termed as the 'wicked' problem [Kirschner, Shum & Carr, 2003]. Wicked problems don't follow the conventional problem solving approach; they are multifaceted problems and require a multidisciplinary approach to solve them and make informed decisions.

To effectively approach 'wicked' problems, visual analytics methods have been adopted to expand the shortcoming of analytical and computational approaches [Keim et al., 2010]. Visual Analytics (VA) is defined as the "Science of analytical reasoning facilitated by interactive visual interfaces" [Cook and Thomas, 2005]. The emerging science of visual analytics leverages human's perceptual and cognitive capabilities to reason, analyze and make sense of complex and dynamic datasets in order to advance the analytical problem solving and decision-making processes. Visual analytics integrates advanced visualization techniques and interactive graphical interfaces with mathematical and computational analytics to support humans' analytical reasoning processes [Thomas and Cook, 2006; Keim et al., 2008]. Visual analytics helps analysts to gain insights into dynamic and 'wicked' problems and ultimately support knowledge construction, problem solving and decision-making. [MacEachren et al., 2004; Boulos et al., 2011]

An example of a 'wicked' problem in public health is injury. Injury is the leading cause of death among North Americans age 1-44 and results in the greatest number of potential years of life lost, compared to other causes of death [Health Canada, 1999]. The causes of injury are many, including motor vehicle crashes, poisoning, drowning and falls, among others [Pike et al., 2010]. Child and youth injuries constitute a major public health concern and an overwhelming financial burden to the Canadian health care system due to the high number of injuries requiring treatment as well as the high costs of hospitalization, rehabilitation services and home health care [SMARTRISK, 2009]. Furthermore, injury is associated with numerous individual, social, environmental and policy related factors, and present multi-dimensional 'wicked' problems to public health professionals and researchers. These ill-structured problems are interconnected and interdependent; they combine various health elements and require a careful study of related factors in order to make appropriate decisions.

Effective analysis of injury data is critical to the development of successful prevention strategies. This includes the identification of trends and patterns in injuries – who is being injured, how they are being injured, and an understanding of the leading causes and associated factors of injury - in order to monitor and improve the health and well being of children and youth in Canada [Pike et al., 2010]. Similar to endemic disease data, injury data are complex and dynamic and therefore need to be carefully examined in order to better inform decisions and actions regarding where to devote resources to reduce and prevent injury occurrences.

The BC Injury Research and Prevention Unit (BCIRPU) at the Child and Family Research Institute (CFRI), BC Children's Hospital has a goal to provide injury researchers, public health practitioners and policy makers with an interactive decision-support technology solution that can help injury stakeholders visually explore, comprehend and interpret dynamic injury

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datasets. As such, we designed the Analytical Injury Dashboard (AID) as a decision-support tool that will empower injury stakeholders and allow them to synthesize critical information from complex and dynamic injury data in order to inform fundamental policies and programs and to strengthen child and youth injury surveillance, prevention and future research.

In previous work by Pike et al. (2010), injury stakeholders adapted the Delphi method approach to develop injury indicators that meet evidence-based criteria and assist in evaluating population health status to initiate actions and prevent injury occurrences. The group of stakeholders conceived a set of 34 injury indicators and categorized them into 5 areas:

1. Overall Health Services Implications.
2. Motor Vehicle Injury.
3. Sports, Recreation and Leisure Injury.
4. Violence.
5. Trauma Care, Quality and Outcomes.

The set of injury indicators were developed according to previous international criteria and standards [Pike et al., 2010] and represent a means to standardize the understanding of injury among children and youth in Canada.

This study synthesizes theories from the Delphi method and the visual analytics methodology to evaluate the use of the AID dashboard to help injury stakeholders build knowledge and make informed decisions about dynamic health situations for child and youth injury prevention initiatives. This study adapts a modified Delphi method approach in a Group Visual Analytics setting to solicit inputs and feedback from real injury experts with real content in a collaborative environment.

The preliminary results of this study are outlined in this paper as follows. The first part of this paper describes the proposed AID dashboard and demonstrates its application using real multidimensional public health data retrieved from the Canadian Hospitals Injury Reporting and Prevention Program (CHIRPP). The reminder of this paper shows the results of the AID pilot testing using the Group Analytics sessions that synthesize multiple injury stakeholders' inputs and enable them to collaboratively work on various scenarios to evaluate the proposed AID dashboard.

2 CHIRPP DATA

Canadian Hospitals Injury Reporting and Prevention Program (CHIRPP) data were used to pilot test the AID dashboard. CHIRPP is a computerized information system that collects and analyzes data on injuries to people (mainly children) who are seen at the emergency rooms of the 10 pediatric hospitals and of 4 general hospitals in Canada. CHIRPP is a unique, richly detailed database of "pre-event" injury information obtained by asking: What was the injured person doing when the injury happened? What went wrong? Where did the injury occur? [CHIRPP, 2009].

For the purpose of this pilot study, we retrieved CHIRPP data for the province of British Columbia for the period 2007-2010 from the Public Health Agency of Canada (PHAC). The data represented child and youth (0-19 years of age) injury cases that visited the BC Children's Hospital emergency department for treatment following an injury. These data are collected on all patients requiring treatment for injury with the purpose to inform child and youth injury prevention initiatives in BC.

A "Data confidentiality Agreement" between BCIRPU and PHAC was signed to permit access to the injury database in order to upload the dataset into the designed AID dashboard and pilot test it. Data was de-identified to preserve patients' privacy and confidentiality, and injury classes with fewer than five cases were not disclosed in the AID dashboard in order to safeguard patients' identities. The study was approved by the University of British Columbia (UBC) research ethics board.

The pre-conceived set of indicators was used to collect data and populate the CHIPRR database. The indicators' data were uploaded into the interactive AID dashboard for pilot testing. The AID dashboard visually represents summative information about these injury indicators. The AID dashboard provides vital information with real content to improve stakeholders' ability to monitor the health status of children and youth, assess health system performance and ultimately assist with decisions and actions.

3 RELATED WORK

Findings from previous research have revealed that visual analytics facilitates data exploration and knowledge construction and subsequently supports the decision-making process [Keim et al., 2010]. Based on existing literature, visual analytics has been extensively adopted to support data analysis and decision-making in various fields including, organizational management [Wang et al., 2010], Geovisual analytics for spatial decision support [Mane et al., 2011; Andrienko et al., 2011], medical visualization for disease diagnosis [Borkin et al., 2011], health analytics [MacEachren et al., 2004], as well as syndromic health surveillance and epidemiologic health analytics [Moore et al., 2008; AvRuskin et al., 2004; Boulos et al., 2011].

Previous research has explained how visual analytics addresses the issue of information overload and enables analysts to transform raw data into salient information and knowledge [Cook & Tomas 2005; Keim et al., 2010]. While many researchers have applied visual analytics to various disciplines, our study focuses on the application of visual analytics to public health issues and in particular, child and youth injury.

The use of advanced information technologies has grown within the healthcare system to enable effective collection of health data [Georgiou, 2002]. With this trend, health professionals appreciate the advantage of integrating visualization techniques into the public health workflow to effectively keep track of health issues, facilitate data exploration, monitor health system functioning and support decision-making [Shneiderman et al, 2013; Moore et al., 2008]. Applying visual analytics to public health problems is vital to convert massive and dynamic health data into salient information and knowledge. Several visual dashboard systems have been used to empower epidemiologists and health professionals with advanced visualizations to facilitate detection and investigation of health incidences [Moore et al., 2008; Cheng et al., 2011; Al-Hajj et al., 2013; Mazzella-Ebstein & Saddul, 2004]. These systems enable health professionals to sift through massive amount of syndromic surveillance health data, detect health anomalies, map their locations, and recognize their trends and changing patterns to make timely decisions and interventions.

Despite this wide use of visual dashboards within the medical and public health sector, there has been a knowledge gap about the effect of using analytical dashboard on facilitating collaborative analytical problem solving and supporting decision making within a real domain application. This paper aims at applying a modified Delphi method approach to design group analytics sessions in order to effectively and efficiently evaluate the integration of collaborative visual analytics into the problem solving and decision-making processes specific to injury prevention stakeholders.

4 ANALYTICAL INJURY DASHBOARD (AID)

Prior to designing and prototyping the AID dashboard, we conducted a series of meetings to understand and document domain tasks in order to inform the design of a visual analytics dashboard that reflects the needs and preferences of injury stakeholders. The meetings served to identify existing domain tasks, the nature of the tasks that need to be conceptualized, the type of injury indicators that should be visualized and the most efficient types of visualizations that should be used to accurately depict the injury indicators data. We compiled the collected data and built the AID dashboard using Tableau Software. Tableau is a commercially available visualization software that uses the Visual Query Language (VisQL) to visually represent large databases through interactive visual interfaces.

We borrowed theories and design guidelines from information visualization and visual analytics to design the AID dashboard [North & Shneiderman, 2000]. We decided to limit the number of views to four co-ordinated views to maintain a balance between acknowledging the end-user's cognitive efforts (i.e. learning efforts, time efforts, memory load, comparison efforts and context swapping efforts) and system requirements (i.e. computational requirements and display space requirements)[Wang et al, 2006].

Based on the literature, we applied principals of visualizations and design guidelines to select the main features and functionalities of the AID dashboard. The design of the AID visual interface was based upon diverse design methods and principles; AID effectively integrates information visualizations guidelines (i.e. color intensity and size) with user interactions (i.e. sort, filter, drill down) and efficient navigation (i.e. Details-on-demand)[Few, 2012; Ware, 2008]. Borrowing from Shneiderman's Information Visualization Mantra, the AID visual interface incorporates visual analytics features and functions including: Overview First, Zoom and Filter, than Details-on-Demand [Shneiderman, 1996].

The types of visualizations were selected to efficiently illustrate trends and patterns in injury data. The system empowers injury stakeholders with a single screen display of multidimensional information including temporality and demographics related to one particular injury issue. Each window view is connected to a full-page visualization with specific functionalities and features to integrate stakeholders' analytical models and facilitate data exploration and data analysis. Every time the stakeholder selects a particular graphical display, a comprehensive visualization will be displayed with advanced analysis capabilities and granularities to enable interaction and in-depth understanding of key injury indicators' performance.

The AID dashboard was built to be intuitive with easily interpreted visualizations that require minimal time and cognitive efforts. The dashboard incorporates two major components: 1) A Visualization Interface component. 2) A Data Analysis component.

The Visualization Interface Component constitutes the AID interface page, which is a single page with summary of all indicators displayed in various graphical representations including stacked bar chart, time trend, and geographic map [Fig.1]. The AID dashboard's external visual representations were built in a way as to amplify injury stakeholders' cognitive and perceptual capabilities and to enhance their reasoning and sense-making processes when dealing with the wicked injury problems [Liu et al., 2010].

The data analysis component of the AID dashboard enables injury stakeholders to interact with the visual representations at various levels of granularities using advanced visualization techniques (i.e. interactive distortion, zooming, filtering, brushing and linking). This interaction facilitates data exploration while minimizing cognitive load. AID analytical features offer temporal, geospatial and structural data to assist stakeholders in gaining comprehensive knowledge and in-depth understanding of the injury indicators data.

Each window provides an analytical aspect related to the performance of main injury indicators. Injury stakeholders can hover the mouse and select one visualization window for further investigation and in-depth analysis of a particular injury indicator and its relevant underpinning factors. Interacting with the tool helps stakeholders quickly build knowledge and identify different dimensions and measures related to the performance of a particular indicator. The AID dashboard offers stakeholders the ability to test and manipulate data to understand underpinning leading causes of injuries, identifying areas of alerting health issues and acquire knowledge needed to make informed decisions.

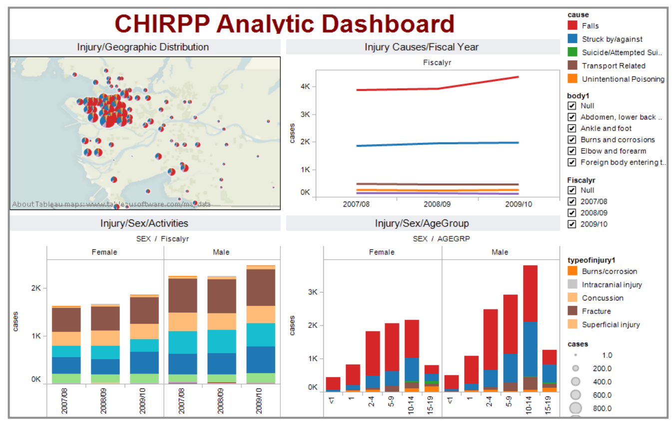

Figure 1: The AID dashboard showing the CHIRPP injury data. It incorporates 4 multiple views: the geospatial visualization, the time trend visualization, and the 2 stacked bar charts visualizations.

5 PROCEDURE

The primary goal of this study was to design a study to pilot test the AID dashboard with real injury stakeholders in a collaborative visual analytics setting. We intended to investigate how the AID dashboard can facilitate multiple injury stakeholders' data exploration as well as enable them to convert complex data into knowledge essential to make informed decisions and take suitable actions.

5.1 Method

Borrowing from the Pair Analytics methodology [Arias-Hermandez et al., 2011], we adopted the Group Analytics (GA) approach to conduct the study. Pair Analytics draws from cognitive science theories [Hutchins, 1995] and the "extreme programming" approach where two programmers collaborate to develop computer software [Beck et al., 2004]. In the Pair Analytics (PA) session, the Subject Matter Experts (SMEs) works collaboratively with the Visual Analytics Expert (VAE) in a one-on-one pair setting to explore the data and solve the analytical problem using the interactive AID dashboard. The Visual Analytics Expert (VAE) is an analyst knowledgeable about the data visualization tools and techniques as well as the design of VA dashboards. SMEs are stakeholders specialized in a specific domain or area. In this study, SMEs are injury stakeholders that possess knowledge, skills and expertise in the field of injury prevention. They have diverse backgrounds ranging from novice public health analysts to senior epidemiologists, and public health medical personnel to public policy specialists.

The Group Analytics method extends the PA methodology and synthesizes techniques from the Delphi method [Okoli et al., 2004] to incorporate the collaboration of multiple Subject Matter Experts (SMEs) with the Visual Analytics Expert (VAE) to solve an analytical problem using the Visual analytics tool. The Group Analytics gather experts in various fields related injury prevention and focus their skills and expertise on the design and evaluation of the AID dashboard in a collaborative and social setting.

An ample number of studies have explored the social aspects of visual analytics where a group of analysts engage in social interactions to solve an analytical problem using visual analytics tools and techniques [Brennan et al., 2006; Heer & Agrawala, 2008; MacEachren, Brewer & Steiner, 2001]. These studies indicated that social interactions and peer collaboration using information visualization tools effectively impact the outcome of the sense-making process and advance the data exploratory analysis process.

Group Analytics is a co-located collaboration of multiple injury stakeholders that uses a single visual display as reference evidence placed in the middle to mediate their activities, conversation, discussions and argumentation. The AID dashboard acts as a single display groupware that fosters collaboration among injury stakeholders to advance the analytical problem solving process and support decision-making.

5.2 Participants

For this study, we used the "purposeful sampling" strategy to select study participants who are injury stakeholders [Creswell & Clark, 2007]. Selected participants were asked to take part in this research study, which involved the use of the AID dashboard, as they are knowledgeable and interested injury prevention stakeholders with adequate knowledge about the explored concept. To ensure representativeness and to cover a broad injury prevention audience, injury stakeholders or SMEs were selected from various age groups, gender, academic background, expertise as well as their clinical and research job focus. They included representatives from provincial and national injury prevention organizations with diverse job titles including injury prevention practitioners, researchers, epidemiologists, medical and health professionals as well as public health policy makers. As well, each participant was purposely selected to represent a constituent group (e.g. medical officers of health) and to solicit general input from constituents before and after the Group Analytics sessions.

5.3 User Study

We conducted two Group Analytics (GA) sessions, each session lasted approximately 30-minutes. Eight injury stakeholders participated in the two Group Analytics sessions (37% male and 63% female). Participants' ages ranged from 25 to 54. Participants sat around a table, similar to a business meeting setting. Prior to the pilot testing, participants were asked to provide information about their background, experience and research interests. They were also asked to explain their work projects in injury prevention and how the tool could help them address existing injury issues and assist with decision-making.

The Visual Analytics Expert (VAE) gave participants an overview tutorial about the AID dashboard and explained its features and functionalities. Participants were given verbal instructions about the sessions' agenda and expectations. Group Analytics sessions were audio and video recorded to capture SMEs' interactions with each other and with the VAE. Screenshots were collected to capture VAE's interaction with the AID dashboard as well as to support the data analysis process. All SMEs signed an informed consent form prior to participating in the study.

During the GA sessions, the facilitator presented the SMEs with two scenarios, each describing a specific analytical problem. The role of the facilitator was to ensure that SMEs keep working and make progress on the given analytical task as well as limit their time to the allocated 30-minute time. The facilitator did not intervene to support the problem solving or decision-making process. We anticipated that the SMEs would collaborate and solve the given problem using the Aid dashboard and with the assistance of the VAE. The two scenarios were as follows:

Scenarios #1: You have been brought together as injury prevention experts for the province. Your task is to inform the development of a targeted intervention that will reduce child/youth injuries presenting to BC Children's Hospital.

Scenario #2: *Nutcase* wants to promote their brand by giving 1000 bicycle helmets. Use the Dashboard to develop a distribution strategy. Explore both concussion and head injuries.

Immediately following the two Group Analytics sessions, SMEs were asked to fill out a self-reported questionnaire. The response rate of the questionnaire was 87%. To enhance the scale's reliability, the questionnaire adopted a 7-point Likert-type scale (i.e. 1- Strongly Agree, 7- Strongly Disagree). The questionnaire was pilot tested with staff and graduate students from the BCIRPU prior to the Group Analytics sessions in order to ensure its validity and test-retest reliability.

6 RESULTS

Audio and video recording together with computer screenshots provided rich understanding about the usability of the AID dashboard and its role in facilitating SMEs' data understanding, as well as supporting their decision-making process. Furthermore, we compiled the questionnaire data and reported the study findings. Participants rated the AID dashboard in terms of the following four characteristics (Table 1):

1. AID dashboard visualization helped injury stakeholders convert data into useful information.
2. AID dashboard stimulated discussions and helped injury stakeholders brainstorm new ideas.
3. AID dashboard enabled injury stakeholders to efficiently and effectively complete the assigned analytical task.
4. AID dashboard helped injury stakeholders share their ideas with other stakeholders.

Metrics	Strongly Agree	Agree	Somehow Agree	No Comments
Useful Information	33%	50%	-	16%
Discussion Stimulating	71%	28%	-	
Task Completion	-	71%	-	-
Ideas Sharing	50%	33%	16%	

Table 1: Compiled data from the questionnaire revealed participants' rating of the 4 main variables following their interactions with the AID dashboard.

Summative information about the SMEs rating of the AID usability was presented in Table 1. The majority of the participants ranked the AID dashboard high in terms of assisting them in converting the complex injury data into useful information that could help them to get insights into the injury data as well as to understand the injury situation and complete the assigned analytical task.

Based on the data compiled from the self-reported questionnaire, Fig 2 highlights the study findings and shows a bar chart that illustrates injury stakeholders' high ranking of the AID dashboard in terms of converting data into useful information, stimulating group discussion and facilitating the completion of the given analytical task.

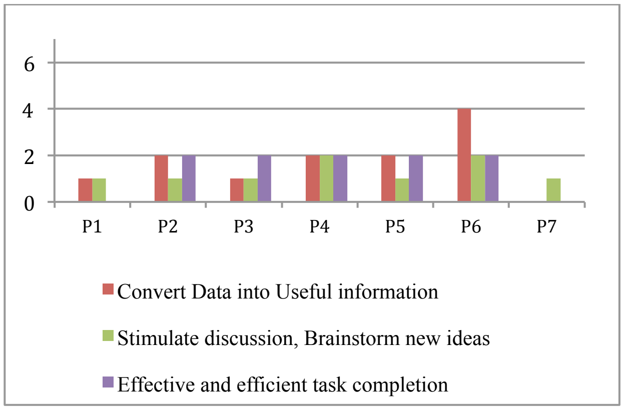

Figure 2. Participants ranked the AID dashboard high in term of information sharing and support for task completion (1-Strongly Agree, 7-Strongly Disagree)

Additionally, we surveyed the impact of the AID dashboard on increasing SMEs' learning experience and building knowledge. We also examined the implications of using the AID dashboard to advance stakeholders' problem solving process and support their decision-making in a face-to-face collaborative setting. Table 2 depicts the results of the data compiled from the questionnaire.

Variables	Strongly Agree	Agree	Somehow Agree
Increase Learning	57%	28%	14%
Support Problem Solving	57%	43%	-
Support Decision-Making	67%	33%	-

Table 2. Compiled data from the questionnaire revealed high rating of the variables following their interactions with the AID dashboard.

As illustrated in Figure 3, stakeholders' ranked the AID dashboard high in terms of increasing learning and supporting problem solving and decision-making.

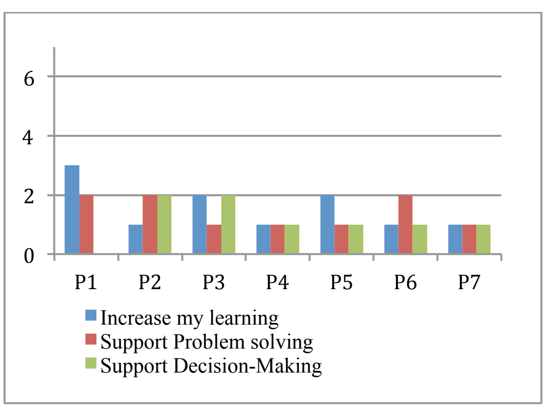

Figure 3. This bar chart represents participants' rating of the AID dashboard in terms of supporting the problem solving and decision-making processes (1- Strongly Agree, 7-Strongly Disagree).

During the collaborative VA sessions, SMEs manipulated the AID visual display and customized the visualizations according to their needs and task requirements. With the assistance of the Visual Analytics Expert (VAE), SMEs interacted with the dashboard to refine the visual representations in a way that enhanced their understanding of the multidimensional injury data and empowered them to converge on a solution and reach a consensus and decide on the best approach to address the injury problem at hand.

7 Discussion

Theses results confirmed our claim that an interactive and analytical dashboard can enable injury stakeholders to gain insights into the dynamic injury data, generate and test new hypotheses, exchange information and expertise in a collaborative setting, and subsequently build knowledge to make informed decisions.

In order to confirm our study findings as well as increase the study generalizability, we supplemented the questionnaire data with a qualitative data analysis of the transcripts generated from the Group Analytics video recordings. Collecting and analysing data from multiple sources enhance our confidence in the study-generated results. During the Group Analytics sessions, injury stakeholders or SMEs collaborated with each other to solve the given task; they discussed different opinions, argued various points of views about the analytical problem and consequently agreed on an ultimate solution to the analytical scenario under investigation.

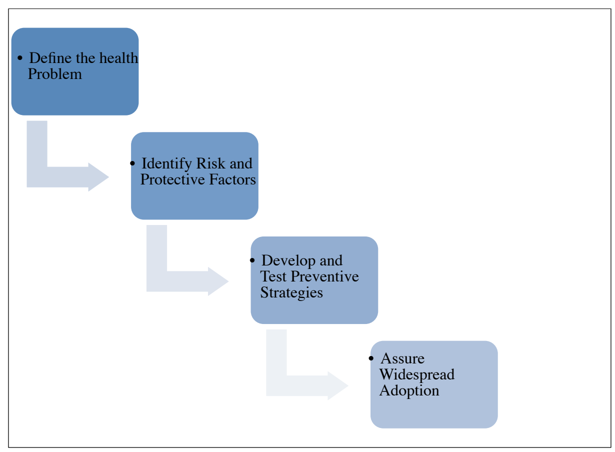

Figure 4. The Public Health Model

During the Group Analytics sessions, SMEs were interested in using the AID dashboard to manipulate the CHIRPP injury data and examine them through the lens of the four stages of the Public Health Model [7][Fig 4]. Firstly, SMEs were interested in identifying the leading injury problem by seeking answers to the their questions such as "What is the leading injury cause?", "Who is the most affected by this injury cause?", "How is this injury cause trending over time?", and "what is the geographic distribution of this injury cause?" [Fig 5]. Injury Stakeholders were able to examine the visual display and identify the highest trending injury cause [Fig 6].

Secondly, based on the knowledge gained from the data exploration, SMEs were able to generate hypotheses and formulate new research questions about the potential risk factors that might be causing the occurrence of specific types of injuries.

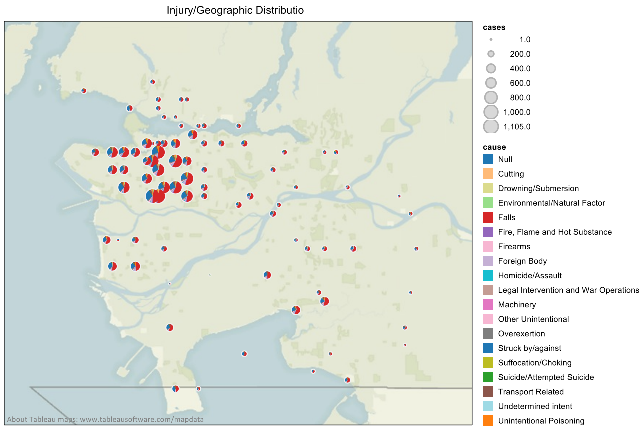

Fig 5. Map view of the AID dashboard to examine the geographic distribution of injury causes across various provinces.

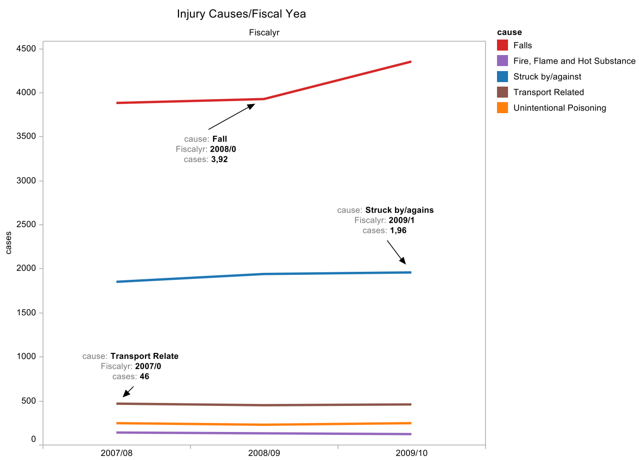

Fig 6. Time Trend View of the AID dashboard to examine the temporal aspects of the top 5 leading causes of injuries and how they are trending over time from 2007 to 2010.

Thirdly, SMEs interpreted the visualizations and used the generated findings as an evidence-based approach to address the injury problem. SMEs tried to use the acquired knowledge to decide on appropriate actions that should be considered in order to control or prevent the likelihood of child and youth injury.

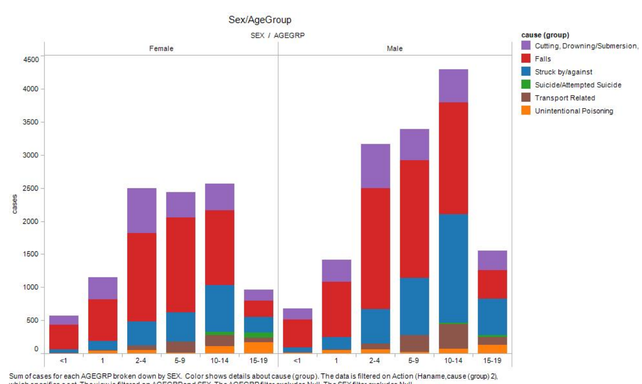

Fig 7. Drill Down of one view of the AID dashboard to examine the leading cause injury among various age groups.

And fourthly, SMEs were not able to actually apply this last phase of the public health model and observe the effect of such long-term decisions during the analytics sessions. However, SMEs were able to identify the impact of previously implemented injury prevention strategies through the observation of the injury yearly and monthly trend lines especially noticing the decreasing number of injury cases following the integration of health promotion programs, deployment of additional health resources as well as enforcement of new public policies.

During the problem solving process, at each stage of the process, SMEs asked the VAE to refine the visualizations and customize the view according to their needs and preferences. The VAE manipulated the AID dashboard interface based on SMEs' suggestions and requests. As demonstrated in the study findings, interacting with the AID dashboard visualizations converted the CHIRPP data into useful information that can be used to identify the leading injury causes [i.e. "Fall" in Fig 6] as well as to classify these injuries across different age groups [Fig 7].

The following extract is retrieved from the group analytics session to illustrate the interaction between multiple SMEs using the AID interactive interface to gain insights into the injury data:

SME 2*: … All of these "Fractures" are severe enough; they should be prevented… where do we go next? I would say we would look at the causes of "Fractures" next.*
SME 8*: yeah.*
SME 3*: Let's look at the "Fractures"*
VAE*: Uh, huhh. So, I'm just going to keep the "Fractures"*
SME 1*: Keep the Fractures,*
VAE*: and then I'm going to add the causes.*
SME 1*: and the causes go up there and that should stack it up…*
SME 2*: Oh Look, it's Fall! [Pointing at the visualization]*

Based on the transcript analysis, we noticed that SMEs were able to identify that "Fractures" were severe enough to flag an alert and therefore they should be prevented. The ability to 'dig deeper' and to identify what causes fractures and therefore, how they might be prevented, was important to the SME's problem solving and decision-making processes.

The dashboard visualizations enhanced injury stakeholders' learning capabilities and gave them a comprehensive picture of the injury problem under investigation [Fig 7]. Three areas that proved injury stakeholders increased learning were:

1. SMEs learned about the CHIRPP data: its potential and its limitations.
2. SMEs learned about the injury situation: they were able to identify the leading causes of injury and what causes represent a burden to the healthcare system.
3. SMEs learned about the tool functions and features. They learned how to manipulate the tool to reflect their research needs.

With the assistance of the Visual Analytics Expert (VAE), injury stakeholders were able to hover the mouse over interesting outliers, dragging and dropping new dimensions and variables into the graph to explore how different data elements influenced the outcome of the analysis. It helps injury stakeholders answer their questions and build knowledge about the causes of different injuries. It also enables them to answer questions about the circumstances of the injuries, i.e. was it a "Fall" from furniture or a "Fall" from a high-rise?

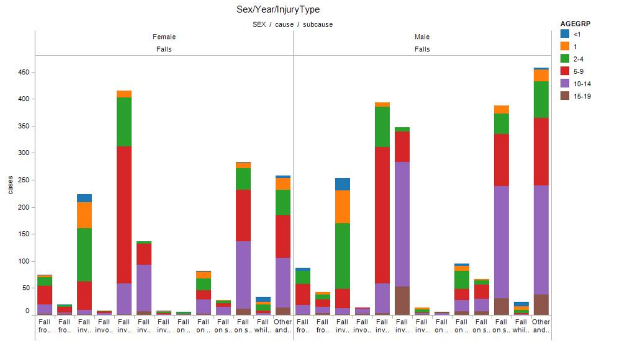

Fig 8. Drill Down of one view of the AID dashboard to examine the "Fall Injury Cause" distribution across various types of injury sub-causes.

Furthermore, the AID dashboard offered SMEs smart analysis and provided them with the granularity to drill down and further investigate the data through multiple filtering and zooming techniques. For instance, injury stakeholders were able to drill down to the age group at risk of "Fall" [Fig. 8] and identify what causes these types of "Fall" (i.e. Playground Equipment and skis).

When communicating and exchanging perspectives, injury stakeholders used the AID dashboard as a common or shared set of visualizations to focus on the analytical problem at hand while maintaining consistency, accuracy and plausibility [Kirschner, Shum & Carr, 2003]. SMEs pointed to the visualization and referred to the AID visual display representation as a shared evidence, which boosted the efficiency of the collaborative problem solving and decision-making process.

The following extract is retrieved from the group analytics session to illustrate the interaction between multiple stakeholders using the AID interactive interface to interpret the visual display and build knowledge to further advance the problem solving process:

***VAE**: So, we have the filter for the type of injury "Fracture" and then it's stacked, we have the different age group…*
***SME 1**: So now you can pick which of the age group…*
***SME 4**: So, what is the purple? [Pointing at the visualization]*
***VAE:** I guess the purple one? [Hovering the mouse over the visualization to display details on demand information], the purple one are…*
***SME 1**: 10-14 and the red ones are 5-9.*
***SME 7**: This seems to be a big category, doesn't it? [Observing the visualization]*
***SME 8**: mostly the purple one, yeah?*
***SME 7**: purple and red*
***SME 3**: Skis and skateboards… yeah*
***SME 8**: Skis, yeah, that's it.*
***VAE**: Do you want to take a deeper look at the purple one?*
***SME 4**: It's ok, I mean what it's telling us is that for younger kids it's playground equipment and for older kids, it's skis, skateboards, ect…*
***SME 8**: right, right*

As depicted in Figure 8 and based on the transcript analysis, the dashboard provided context to situate the injury problem and accurately judge the injury situation, which proved to be vital to advance SMEs' problem solving and decision-making processes. For instance, injury stakeholders were able to compare the different categories of injuries in order to specify which one is the highest compared to other causes or types of injury and therefore need to be address and prioritize the intervention (i.e. the purple bar and the red bar correspondingly representing the highest rates of injuries and therefore require immediate health interventions).

Towards the end of each Group Analytics sessions, SMEs made verbal conclusions to address the posed scenario based on the available information and knowledge gained from the injury data using the AID dashboard. One of the participants then reported the group final decision by conveying their consensus and agreement and presenting the ultimate solution to the injury problem.

8 Conclusion

This study enabled us to empirically understand and document injury stakeholders' experience interacting with the AID dashboard and therefore tailor the dashboard to better fit their preferences and needs. Furthermore, it enables us to identify stakeholders' analytical and reasoning processes when making decisions in order to inform the design of innovative collaborative visual analytics tools and techniques as well as advance the Group Analytics methodologies.

This study incorporated a number of limitations and challenges that we acknowledge. Firstly, this study investigated a hypothetical injury issue and therefore injury stakeholders were not making actual decisions. Secondly, the study sample was relatively small, which may limit the generalizability of the study and its applicability on a larger injury stakeholders' population. However, as stated, each SME was purposely selected because of their strong knowledge and expertise in injury prevention and also their credibility and position to represent constituent peers. Thirdly, during the course of the Group Analytics session, it was essential to take into consideration the challenges and obstacles that might face the collaborative decision-making process. These challenges include but not limited to the number of stakeholders in each session, the discrepancy in knowledge and expertise among injury stakeholders, SMEs' biases, as well as the levels of authority of participating injury stakeholders. In addition, we need to emphasize the need to have a trained facilitator to steer and manage the group analytical process. Facilitators play a major role in promoting collaboration among stakeholders and converging and guiding the group analytical session toward a solution, consensus or optimal decisions to the issue under investigation.

Furthermore, considerations for patients' privacy and confidentiality must be taken into account when designing analytical dashboards to visually depict health data. Protecting patients' privacy and confidentiality is of paramount importance within the healthcare sector. In order to maintain confidentiality and privacy standards and avoid pinpointing patients based on their geographic locations, the analytical dashboard must be developed and managed so as not to display injury classes with fewer than five cases. Data must be anonymous, removed of any personal identifiers and aggregated so that patient identity and privacy is always protected. Despite these limitations, the study findings clearly reveal the advantages of integrating analytical dashboard as a decision-support tool to synthesize information from multidimensional and dynamic data.

These research results present the preliminary evaluation of the AID dashboard by multiple stakeholders in a collaborative setting. The next phase of this research work will discuss the testing of the AID dashboard in real domain application within the injury prevention program. The testing will include the Graphical User Interface testing as well as the usability and compatibility testing. A series of SMEs interviews will be conducted to follow up on SMEs expectations and experience when integrating the AID dashboard into their real domain applications and its impact on the problem solving and decision-making process within the healthcare system.

Future research work should take into consideration this study's limitations and suggest the design of novel group analytics as well as innovative analytical dashboard with advanced visual analytics techniques to support stakeholders' problem-solving and decision-making processes. Additional research is needed to explore the implications of integrating visual analytics on health informatics within the healthcare sector.

9 Acknowledgment

We would like to thank the injury stakeholders for taking part in this study. We would also like to thank the CHIRPP team at PHAC, and the CIHR Team in Child and Youth Injury Prevention for their support and valuable feedback.

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