

Original Investigation

On Effective Graphic Communication of Health Inequality: Considerations for Health Policy Researchers

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Policy Points:

- Effective graphs can be a powerful tool in communicating health inequality. The choice of graphs is often based on preferences and familiarity rather than science.
- According to the literature on graph perception, effective graphs allow human brains to decode visual cues easily. Dot charts are easier to decode than bar charts, and thus they are more effective. Dot charts are a flexible and versatile way to display information about health inequality.
- Consistent with the health risk communication literature, the captions accompanying health inequality graphs should provide a numerical, explicitly calculated description of health inequality, expressed in absolute and relative terms, from carefully thought-out perspectives.

Context: Graphs are an essential tool for communicating health inequality, a key health policy concern. The choice of graphs is often driven by personal preferences and familiarity. Our article is aimed at health policy researchers developing health inequality graphs for policy and scientific audiences and seeks to (1) raise awareness of the effective use of graphs in communicating health inequality; (2) advocate for a particular type of graph (ie, dot charts) to depict health inequality; and (3) suggest key considerations for the captions accompanying health inequality graphs.

Methods: Using composite review methods, we selected the prevailing recommendations for improving graphs in scientific reporting. To find the

origins of these recommendations, we reviewed the literature on graph perception and then applied what we learned to the context of health inequality. In addition, drawing from the numeracy literature in health risk communication, we examined numeric and verbal formats to explain health inequality graphs.

Findings: Many disciplines offer commonsense recommendations for visually presenting quantitative data. The literature on graph perception, which defines effective graphs as those allowing the easy decoding of visual cues in human brains, shows that with their more accurate and easier-to-decode visual cues, dot charts are more effective than bar charts. Dot charts can flexibly present a large amount of information in limited space. They also can easily accommodate typical health inequality information to describe a health variable (eg, life expectancy) by an inequality domain (eg, income) with domain groups (eg, poor and rich) in a population (eg, Canada) over time periods (eg, 2010 and 2017). The numeracy literature suggests that a health inequality graph's caption should provide a numerical, explicitly calculated description of health inequality expressed in absolute and relative terms, from carefully thought-out perspectives.

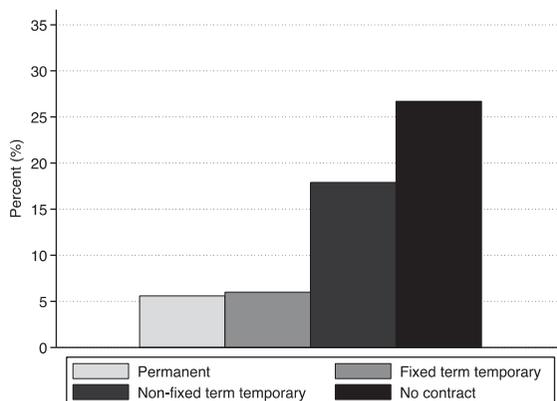
Conclusions: Given the ubiquity of graphs, the health inequality field should learn from the vibrant multidisciplinary literature how to construct effective graphic communications, especially by considering to use dot charts.

Keywords: health inequality, graphs, communication.

GRAPHS ARE AN ESSENTIAL TOOL FOR COMMUNICATING health inequality, a key health policy concern shared by many jurisdictions across the globe.¹⁻³ Graphs are often used to display differences in various health outcomes and determinants of health. They can be found in any high-profile health report with a focus on health inequality, such as the World Health Organization's *Commission on Social Determinants of Health*³; a subsequent review of health inequality in the United Kingdom, *Fair Society Healthy Lives*⁴; and the final review of *Healthy People 2010*,⁵ a decennial national road map for the health of Americans. In each of these reports, we find numerous graphs, and they frequently are bar charts, such as those in Figures 1a, 1b, and 1c.

The choice of graphs or the use of bar charts to communicate health inequality is often driven by personal preferences, aesthetics, and familiarity. As a communication tool, however, graphs should be *effective*; that is, they should accurately convey the intended message to

Figure 1a. Bar Chart Depicting Health Inequality: Prevalence of Poor Mental Health Among Male Manual Workers in Spain by Type of Contract^a

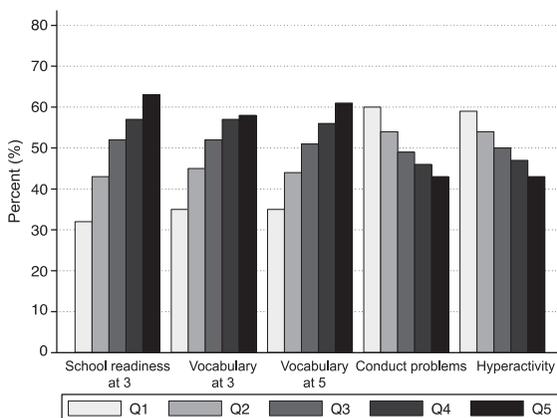


^aThis figure is from the WHO *Commission on Social Determinants of Health*, p. 5.³

the target audience. Ineffective graphs add nothing and can even be misleading.^{6,7} Despite the routine use of graphs to communicate health inequality, researchers and policymakers often do not know which type of graph communicates health inequality information most accurately, and why. This is unfortunate. Effective graphs are a powerful tool in communicating a wide range of quantitative information, and they can be particularly useful in describing the complex concept of health inequality.⁸ For example, the same difference in health can be perceived and numerically expressed as both absolute (eg, 10-year) and relative (eg, 50% greater) differences.^{9,10} A graph can aid these numeric explanations.

The question of effective graphs has a long history in such diverse disciplines as statistics, psychology, psychophysics, human factors, and informatics.^{6,7,11-20} Furthermore, the field of health risk communication has paid considerable attention to using effective graphs in communicating *health* information.²¹⁻²⁴ To date, health inequality researchers and

Figure 1b. Bar Chart Depicting Health Inequality: Average Percentile Scores for Indicators of School Readiness by Parental Income Group, 2008^a

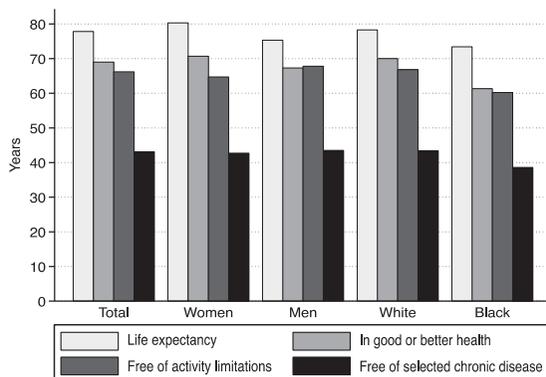


^aThis figure is from Marmot, Allen, Goldblatt, et al., *Fair Society Healthy Lives*, Figure 2.22.⁴

policymakers have not taken full advantage of this vast, rich literature. The first objective of our article, therefore, is to raise awareness among health policy researchers of the effective use of graphs in communicating health inequality. To do this, we first provide a brief overview of the most common recommendations for improving graphs in scientific reporting, with particular attention to the literature on graph perception.^{6,18,25} This literature has hypothesized and tested how human brains respond to visual cues and has established theories of visual perceptions and empirical evidence to derive principles of effective graphs.

The second objective of our article is to advocate for dot charts,^{6,25,26} one type of graph that the literature on graph perception regards as a more effective alternative to commonly used bar charts to display health inequality information. This literature shows that bar charts are often not the best choice and can even be misleading. We then demonstrate why dot charts are a good choice for depicting health inequality.

Figure 1c. Bar Chart Displaying Health Inequality: Life Expectancy and Measures of Healthy Life Expectancy at Birth, 2006–2007^a



^aThis figure is from the final review of *Healthy People 2010*, Figure O-5.⁵

The final objective of our article is to suggest key considerations for captions accompanying health inequality graphs. Effective graphs, including well-designed dot charts, should be as self-explanatory as possible with clear and appropriate captions. However, the question of how best to explain health inequality presented in graphic displays is often overlooked. To meet this final objective, we draw from the numeracy literature in health risk communication.^{21,23,27-40}

Before proceeding, a few caveats are in order. First, in this article, we focus on graphs that are static visual displays of quantitative information. Interactive or animated visual displays are beyond the scope of our article. Second, graphs have many purposes, including persuasion for behavioral change, attention, or aesthetics.^{24,41} Our focus is exclusively on clear, accurate communication as measured by the resulting knowledge, not the degree of emotion or motivations to address inequalities evoked by graphs. Finally, we assume a homogeneous, relatively well-educated audience with reasonably good numeracy skills, and we caution that applying our recommendations to an audience with heterogeneous graphic comprehension will require further considerations.⁴²

Effective Graphs

Anyone trained in disciplines that use quantitative data is likely to have been exposed to discussion regarding how best to produce effective graphs. A number of authors, in a wide range of disciplines, have provided recommendations for presenting quantitative data in a visual format. Table 1 lists a sample of such recommendations based on 17 selected studies.^{7,11,13-17,19,20,43-50} Because of the voluminous literature on graphs and the lack of established systematic methods to review the literature, we used composite review methods that included keyword searches, backward and forward citation searches, and snowball methods to identify the 17 studies. We reviewed only summary articles, reviews, and those that provided suggestions and recommendations. We did not review primary studies. Although our search was not exhaustive, it offers an overview of the most common recommendations for visual displays.

The commonsense, rule-of-thumb recommendations summarized in Table 1 are helpful, and indeed, following them would improve many graphs. Some of the well-known recommendations (eg, optimize the data-to-ink ratio [ie, the amount of ink used to present data to the total amount of ink used for the graph], and avoid “chartjunk” [ie, clutter]) come from Edward Tufte, who is arguably one of the most influential data visualization pioneers. In his widely circulated books,^{7,48-50} Tufte shows and discusses what effective data visualization looks like and why it is effective.

To explore the origins of recommendations summarized in Table 1 and to explain what an *effective* graph actually is, we examined the literature on graph perception.^{6,18,25,41,51} This literature is large, and here we highlight works of Stephen Kosslyn and William Cleveland, two giants in this field (for a comprehensive review of the perception of graphs, see Lewandowsky and Spence⁵¹; and for a historical review of the development of graphs, see the Milestones Project by Friendly and Denis,⁵² <http://datavis.ca/milestones/>).

Kosslyn defines effective graphs as those that respect perceptual, cognitive, and memory processes natural to human brains. He offers 8 psychological principles of effective graphs, summarized in Table 2.¹⁸ It is easy to make connections between Kosslyn’s principles in Table 2 and some of the typical recommendations listed in Table 1. For example, the principle of relevance states, “Communication is most effective when

Table 1. Selected Recommendations for Visually Presenting Quantitative Data^a

Necessity of Graph

- Define carefully what needs to be communicated and determine whether a text, table, or graph is the best way to communicate the information.
- Determine the audience's experience, knowledge, expectations, and information needs (2, 8).

General Considerations

- Optimize the data-to-ink ratio (the amount of ink used to present data to the total amount of ink used for the graph) (1).
- Encourage the eye to compare different pieces of data (3, 4).
- Avoid "chartjunk"; do not clutter graphs with what you do not need (1).

Types of Graphs

- Identify essential variables and their key characteristics (eg, trend, frequency) you wish to communicate.
- Use line graphs for trends.
- Use bar graphs for discrete data and absolute or relative frequencies, but not for point estimates or data means.
- Use scatter plots and line plots to show association between a pair of variables.
- Use scatter plots, one-way plots, or more specialized graphs to show a distribution of data.

Representation of Data

- Use symbols, bars, and lines to enhance discriminability among data (3, 4, 5).
 - Use thick symbols and lines to ensure adequate reproduction.
 - Avoid overlapping data symbols (3, 4).
 - Be consistent, if possible, with the use of symbols, bars, and lines across similar graphs (8).
 - Choose colors carefully: (a) select an appropriate color scheme based on the type of data; (b) when communicating categorical information, use different colors well separated in the spectrum; (c) for continuous data, if necessary, use saturation or darkness of the same colors; and (d) avoid colors that are difficult for color-blind people (3, 4, 5, 6).
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Continued

Table 1. *Continued*

Auxiliary Elements

- Select meaningful axis ranges, and consider carefully whether to include zero in each axis; if excluded, ensure its absence is clearly signaled (3, 4).
- Use the same axis scales and ranges on graphs that are to be compared (8).
- Carefully choose aspect ratio (relative height and width) and data density (graph size) to avoid misrepresenting the data.
- Design backgrounds to set off the graph, not compete with it (4).
- Use grid lines, if they assist accurate interpretation, and make secondary lines lighter in weight, color, or style.

Titles, Labels, Legends, and Captions

- Use clear and informative titles.
 - Define and label all elements of the graph, including all axes, without redundancy.
 - Use horizontal labels, but avoid long horizontal labels extending beyond the graph.
 - Consider using self-explanatory symbols rather than a remote legend.
 - Write a legend that makes the graph self-explanatory.
 - Use captions to annotate important aspects of graphs so graphs stand on their own.
 - Position annotation (including legends) to aid interpretation, not to distract from the message.
 - Use simple phrases consistent with text labels and define all abbreviations and symbols (8).
 - Use font sizes large enough for easy reading, suitable for reproduction, and appropriate for the size of the graph and the graph area.
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^aThe numbers of Kosslyn's principle(s) summarized in Table 2 are given here in parentheses.

neither too much nor too little information is presented.” This principle corresponds to the importance of simplicity of graphs emphasized by two well-known recommendations by Tufte: “optimize the data-to-ink ratio” and “avoid chartjunk.” The numbers in brackets following a recommendation in Table 1 correspond to a specific Kosslyn principle when relevant.

Table 2. Kosslyn's Psychological Principles of Effective Graphs^a

Principle	Explanation
1 Relevance	Communication is most effective when neither too much nor too little information is presented.
2 Appropriate Knowledge	Communication requires prior knowledge of relevant concepts, jargon, and symbols.
3 Salience	Attention is drawn to large perceptible differences.
4 Discriminability	Two properties must differ by a large enough proportion or they will not be distinguished.
5 Perceptual Organization	People automatically group elements into units, which they then attend to and remember.
6 Compatibility	A message is easiest to understand if its form is compatible with its meaning.
7 Informative Changes	People expect changes in properties to carry information.
8 Capacity Limitations	People have a limited capacity to retain and to process information and will not understand a message if too much information must be retained or processed.

^aKosslyn (2006).¹⁸

While Kosslyn's principles are helpful for improving any type of graph, Cleveland and colleagues provide guidance on why we should choose one type of graph over another (eg, bar charts vs pie charts). Their premise is that a graph's effectiveness should be understood in terms of visual *encoding* and *decoding* of information. Graph creators encode quantitative information, and graph users visually decode the information. Effective graphs are those that allow a quick and easy decoding process. Thus, to create effective graphs, we must understand and respect the human brain's decoding mechanism.²⁵

Based on theories of visual perception, Cleveland and colleagues derived 10 *elementary perceptual tasks* that the human brain performs

when extracting quantitative information from graphs. Through a series of experiments, they found that the human brain performs these tasks at different levels of accuracy. They grouped these 10 elementary perceptual tasks into 6 levels of accuracy, from most to least accurate: (1) position along a common scale; (2) position along nonaligned scales; (3) length, direction, and angle; (4) area; (5) volume and curvature; and (6) shading and color saturation. Graphs using more accurate elementary perceptual tasks are less taxing to the brain and yield judgments with fewer errors. In levels 3, 5, and 6, Cleveland and colleagues grouped together multiple perceptual tasks because their experiments did not reveal a precise order.²⁵

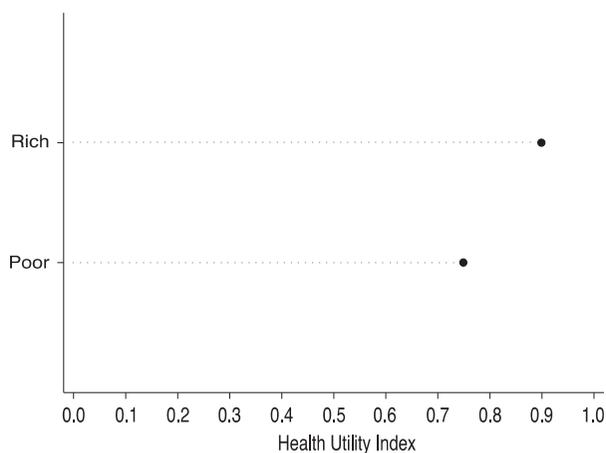
Cleveland and colleagues explained how these elementary perceptual tasks underlie common types of graphs and how a better understanding of these tasks might help us choose one type of graph over another. Of particular relevance to health inequality researchers and policymakers is their discussion regarding bar charts.^{6,25,26} As shown in Figures 1a, 1b, and 1c, bar charts are a very common type of graph in the health inequality literature. For the 10 elementary perceptual tasks, bar charts require perceptual judgments regarding the position along a common scale, length, and/or area. The judgment regarding area reflects the need to scrutinize individual bars in a bar chart. But bars can be misleading because the width of the bars is often arbitrary and thus may visually encode unfounded significance in the quantitative information. For example, the bars used in Figure 1a are wider than those in Figure 1b, and wide bars may overstate and thin bars may understate significance. Cleveland and colleagues suggest that the judgment regarding area could be avoided by using dot charts.

Dot Charts

Definition

A dot chart is a 2-dimensional graph displaying quantitative information. Many different styles of graphs have been called dot charts, but the specific dot charts we advocate in this article are those that Cleveland proposed.^{6,25,26,41} One axis of the graph (usually the horizontal) is a scale for the numeric values, and the other axis (usually the vertical) provides labels associated with these numeric values. Typically, dots connect each label with its associated value. Sometimes the dots go all the way across

Figure 2a. Dot Chart Displaying Inequality in the Health Utilities Index^a Between the Rich and the Poor^b in Canada^c



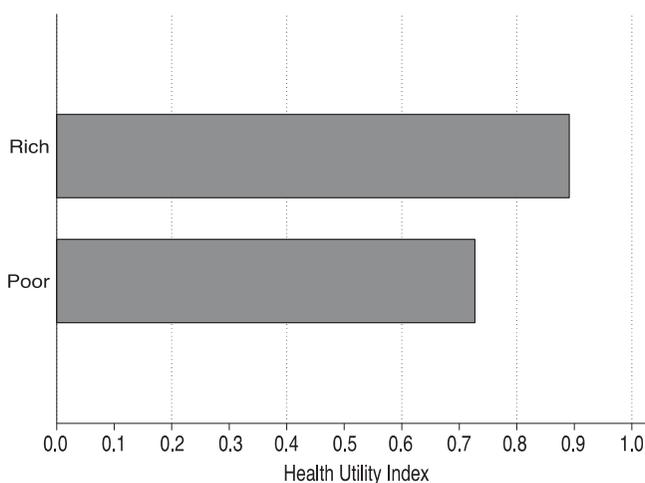
^aThe Health Utilities Index (HUI) is a health-related quality-of-life measure. The HUI Mark 3, used in this figure, takes values between -0.36 and 1.00 , where 0.00 indicates health status as bad as death, 1.00 indicates full health, and negative values indicate a health state worse than death.

^bThe poor is the lowest-income quintile group, and the rich is the highest-income quintile group. This figure shows the mean HUI scores for the poor and the rich.

^cData are from Canadian Community Health Survey 2014.⁵⁴ Data are weighted to represent the noninstitutionalized Canadian population.

the entire width of the graph. Figure 2a is an example of a simple dot chart. It plots the average health of the rich and the poor in Canada, where health is measured by the Health Utilities Index Mark 3 (HUI), which has values between -0.36 and 1.00 , where 0.00 indicates health status as bad as death, 1.00 indicates full health, and negative values indicate a health state worse than death.⁵³ As discussed in the previous section, a dot chart displays the same information as a bar chart (see Figure 2b, which has horizontal bars for easier comparison to a dot chart). A side-by-side comparison of Figure 2a (dot chart) and Figure 2b

Figure 2b. Bar Chart Displaying Inequality in the Health Utilities Index^a Between the Rich and the Poor^b in Canada^c



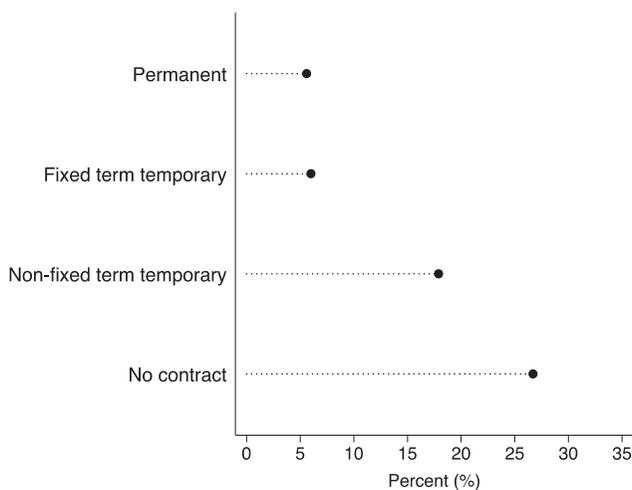
^aThe Health Utilities Index (HUI) is a health-related quality-of-life measure. The HUI Mark 3, used in this figure, takes values between -0.36 and 1.00 , where 0.00 indicates health status as bad as death, 1.00 indicates full health, and negative values indicate a health state worse than death.

^bThe poor is the lowest-income quintile group, and the rich is the highest-income quintile group. This figure shows the mean HUI scores for the poor and the rich.

^cData are from Canadian Community Health Survey 2014.⁵⁴ Data are weighted to represent the noninstitutionalized Canadian population.

(bar chart) shows that both graphs make an explicit connection between the data points and their labels by means of dotted lines (in the dot chart) or bars (in the bar chart). To convey the same information, the dot chart requires only a judgment regarding the position along the common scale, whereas the bar chart requires additional judgments regarding the length and/or area. Thus, according to Cleveland and colleagues, the dot chart is more accurate than the bar chart. Moreover, as we pointed out earlier, the additional visual decoding needed to interpret the bars in the

Figure 3a. Dot Chart Displaying Health Inequality: Prevalence of Poor Mental Health Among Male Manual Workers in Spain by Type of Contract^a

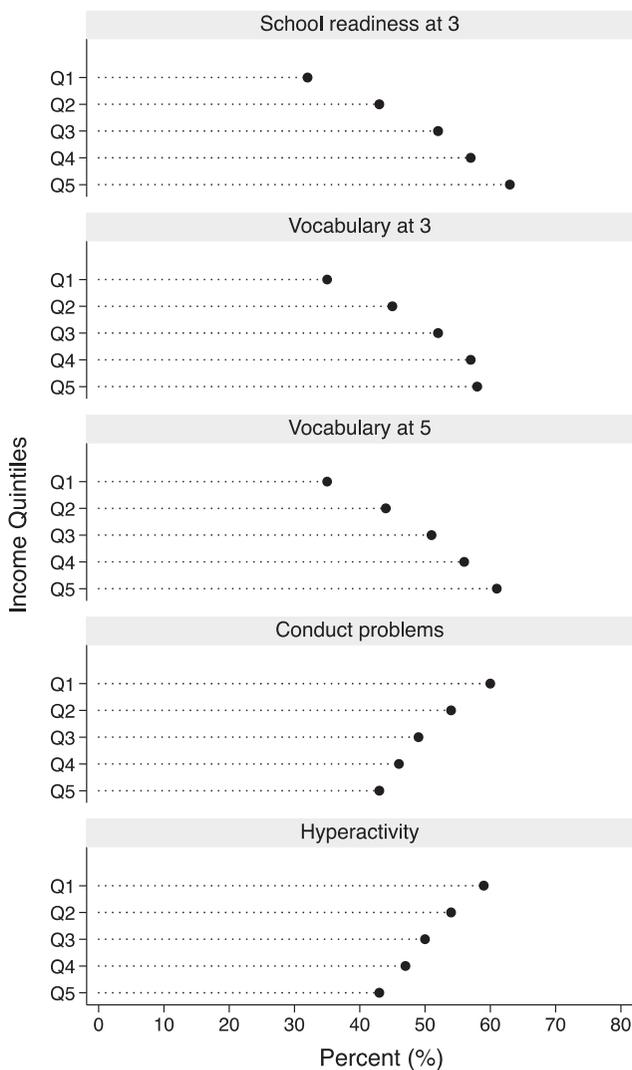


^aThe information in this figure is from the WHO *Commission on Social Determinants of Health*, p. 5, and is the same for Figure 1a.³

bar chart may also reduce the accuracy of the bar chart compared to that of the dot chart.

Dot charts can be used effectively for cases both with and without meaningful baselines. That is, we can determine whether meaningful baselines exist according to the type of the variable used (ie, levels of measurement). For example, the percentage (a ratio-level variable) used in the bar charts in Figures 1a and 1b has a meaningful zero. In this case, the dots can stop at zero, so the graph encodes the length from the baseline to the value of interest, as shown in Figures 3a and 3b. These graphs display the same information as do Figures 1a and 1b, respectively. The original data used for Figure 1b are test scores. Suppose we drew a dot chart using test scores rather than converting them into percentiles. This would create a dot chart similar to Figure 3b, but the dots would go through the data points to extend the entire width of the graph. This is because,

Figure 3b. Dot Chart Displaying Health Inequality: Average Percentile Scores for Indicators of School Readiness by Parental Income Group, 2008^a



^aThe information in this figure is from Marmot, Allen, Goldblatt, et al., *Fair Society Healthy Lives*, Figure 2.22, and is the same for Figure 1b.⁴

technically speaking, test scores (ie, an interval-level variable) do not have a meaningful zero and only the differences between test scores are meaningful. Extended dots emphasize differences between data points and de-emphasize a potentially inaccurate judgment regarding length.⁵⁵

When the key message of a dot chart is to emphasize the differences between data points, we can either add horizontal lines or change the minimum and maximum values of the scale (the horizontal axis). Changing the minimum and maximum values requires careful consideration, for 3 reasons. First, we should not overstate or understate the significance of a difference by changing the minimum and maximum values. Second, changing the minimum value may sometimes require omitting zero in dot charts even when a meaningful baseline exists. Whether graphs must include zero is one of the most controversial questions in graphic displays, with no clear consensus on the answer. In 1954, Darrell Huff recommended the inclusion of zero in graphs in his widely popular book, *How to Lie With Statistics*.⁵⁶ Cleveland disagreed, stating that having zero in every graph was not an absolute requirement.⁶ When the inclusion of zero brings the data points so close together that they interfere with comprehension, excluding zero may be justified. Third, when assessing health inequality, not only the size but also the location of a difference may be relevant. Consider a population with the same difference in the HUI between the poor and the rich, as shown in Figure 2a, but much sicker (eg, the HUI for the poor is 0.25 and the HUI for the rich is 0.40, as opposed to 2a, in which the HUI for the poor is 0.75 and the HUI for the rich is 0.90). Although the absolute difference in the HUI is the same in both populations (0.15), we might consider its significance differently depending on where the difference takes place along the scale between zero and one. We might say the difference of 0.15 when both the rich and the poor are relatively healthy may not be as significant as the same difference when they both are much less healthy. Showing the entire scale between zero and one clearly reveals the location of health inequality.

Accommodating Various Health Inequality Information

A key advantage of using dot charts is their ability to present a large amount of information in a limited space and to group data in a flexible manner. This feature works well in the context of health inequality.

Indeed, dot charts can effectively accommodate typical health inequality information beyond the simple case presented in Figure 2a.

To show the versatility of dot charts in the context of health inequality, we start by explaining how health inequality are typically described using a simple formula: health variable (H) (eg, life expectancy) by inequality domain (D) (eg, income) with domain groups (G) (eg, poor and rich) in a population (P) (eg, Canada) over time periods (T) (eg, 1950, 2000, and 2015), or H by D with G in P over T.

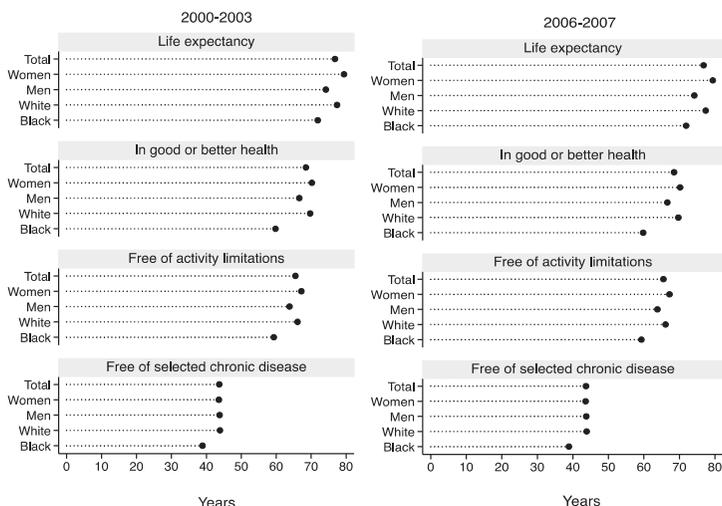
For example, in Figure 2a, H is the HUI, D is income, G are the groups poor and rich, P is Canada, and T is 2014.

To construct a dot chart, it is helpful to think of how many data points to display in the dot chart as the number of H, D, G, P, and T: How many health variables, inequality domains, groups in each inequality domain, populations, and time periods are there to display?

In the simplest case concerning health inequality, such as that presented in Figure 2a, the number of H, D, P, and T is 1 for each, and for G it is 2. This is not typical. The health inequality cases usually depicted in graphs have a greater number of H, D, G, P, and/or T than in the simplest case. For example, in Figure 1a, the number of G is 4 (ie, permanent, fixed-term temporary contract, non-fixed-term temporary contract, and no contract), and the number of H (ie, prevalence of poor mental health), D (ie, contract type), P (ie, Catalonian men), and T (ie, 2002) is 1. As Figure 3a shows, by adding labels, dot charts can accommodate a greater number of G. While displaying the same information as Figure 1a (bar chart) does, Figure 3a (dot chart) uses less ink and avoids the unnecessary judgment regarding area.

When the number of H, D, P, and/or T increases, we can use *multiway* dot charts,^{6,41} which are a vertical and/or horizontal combination of dot charts. For example, Figure 3b displays inequalities in the 5 outcomes (H: school readiness at age 3, vocabulary at age 3, vocabulary at age 5, conduct problems, and hyperactivity) originally displayed in Figure 1b. In addition, Figure 3c adds one more time period to the data displayed in Figure 1c. In Figure 3c, the numbers of H, D, G, P, and T are 4, 2, 2, 1, and 2, respectively, plus data points for “total,” resulting in 40 data points. When the number of data points increases, the dot chart’s cleaner and simpler displays become evident when comparing Figures 3b and 1b and Figures 3c and 1c side by side. As Figure 3c shows, multiway dot charts can, in principle, organize and clearly present a relatively large number of data points. Nonetheless, with the simultaneous increase in

Figure 3c. Dot Chart Displaying Health Inequality^a: Life Expectancy and Measures of Healthy Life Expectancy at Birth, 2000-2003^b and 2006-2007



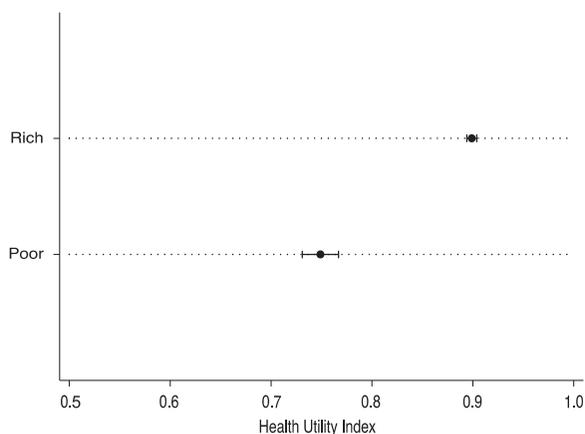
^aThe information in this figure is from National Centre for Health Statistics, *Healthy People 2010*, Figure O-5, with additional data for 2000-2003 from Tables O-3 and O-4.⁵

^bData for the outcome “Free of selected chronic disease” are for 2002-2003, and data for other outcomes are for 2000-2001.

the numbers of H, D, G, P, and T, clutter may result. To avoid this, a dot chart can be divided into 2 or more charts for more effective communication.

Another consideration for multiway dot charts is how best to organize the data points. For example, although Figures 1c and 3c have the same information, Figure 1c emphasizes the differences between health outcomes in each population group (ie, women, men, white, and black), while Figure 3c highlights the differences among the population groups in each health outcome. Multiway dot charts offer a wide range of organizational options, and the best one depends on the intended message.

Figure 4a. Dot Chart Displaying Inequality in the Health Utilities Index^a Between the Rich and the Poor^b in Canada,^c with Uncertainty Bounds^d



^aThe Health Utilities Index (HUI) is a health-related quality-of-life measure. The HUI Mark 3, used in this figure, takes values between -0.36 and 1.00 , where 0.00 indicates health status as bad as death, 1.00 indicates full health, and negative values indicate a health state worse than death.

^bThe poor is the lowest-income quintile group, and the rich is the highest-income quintile group.

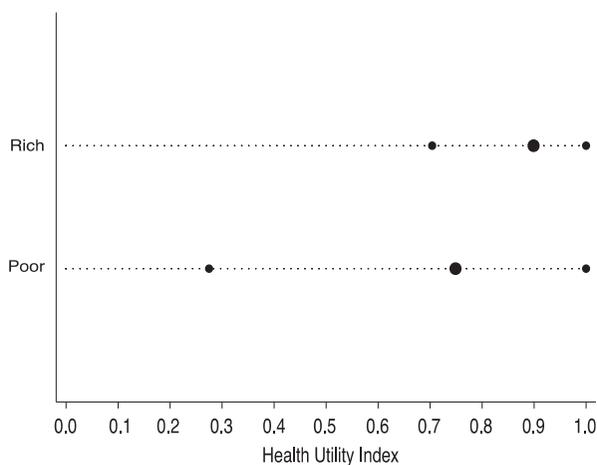
^cData are from Canadian Community Health Survey 2014.⁵⁴ Data are weighted to represent the noninstitutionalized Canadian population.

^dThis figure shows the mean HUI scores for the poor and the rich as well the 99% confidence intervals.

Displaying Uncertainty and Within-Group Inequality

Another attractive feature of dot charts is their ability to display information beyond point estimates. An obvious application of this feature is to add uncertainty bounds to the group averages depicted by dots. For example, Figure 4a adds 99% confidence intervals to the group averages in Figure 2a. Of course, bar charts can add uncertainty bounds, but the amount of ink used in a bar chart can obscure the illustrations and

Figure 4b. Dot Chart Displaying Within-Group and Between-Group Inequality in the Health Utilities Index^a Between the Rich and the Poor^{b,c} in Canada^d



^aThe Health Utilities Index (HUI) is a health-related quality-of-life measure. The HUI Mark 3, used in this figure, takes values between -0.36 and 1.00 , where 0.00 indicates health status as bad as death, 1.00 indicates full health, and negative values indicate a health state worse than death.

^bThe poor is the lowest-income quintile group, and the rich is the highest-income quintile group.

^cThis figure shows the mean and the 10th and the 90th percentile HUI scores for the poor and the rich.

^dData are from Canadian Community Health Survey 2014.⁵⁴ Data are weighted to represent the noninstitutionalized Canadian population.

hamper clear communication (for a side-by-side comparison of a bar chart and a dot chart, both with uncertainty bounds, see Figures 11 and 12 in Cleveland²⁶).

This feature of dot charts also improves the visualization of within-group inequality. Studies have shown considerable overlap in health status across groups and large within-group inequality.⁵⁷⁻⁵⁹ For example, Figure 4b adds distributional information to the comparison of the

group averages in Figure 2a. Specifically, Figure 4b adds the information about the HUI scores of the 10th percentile and the 90th percentile of the population. The extended dot chart in Figure 4b is similar to a box plot, which also displays within-group and between-group inequality. Currently, the literature is not entirely clear about how best to present within-group inequality. At a minimum, within-group inequality provides a better understanding of health inequality. We might even argue that a clear justification needs to be made as to why one aspect of health inequality (between-group inequality) should be prioritized over another (within-group inequality). Making within-group inequality visible can encourage an appreciation of the whole scope of health inequality.

How to Explain Health Inequality Graphs

Whether using a dot chart or another type of graph, effective graphic communication does not end with a well-designed graph; we must also clearly explain the graph. Verbal and numeric explanations of the information presented in the graph help clarify even carefully constructed graphs. A caption is one way to ensure that a graph is always paired with a supplementary explanation. Indeed, using a caption is one of the most widely accepted recommendations for visually presenting quantitative data (see Table 1).

An appropriate caption for a health inequality graph deserves careful thought. Concerns for health inequality are often ethical, as apparent in the ongoing debate about which differences in health are of ethical and social concern or are *inequitable*.⁶⁰⁻⁶⁷ Fundamental to this debate is an accurate description of the situation about which an ethical judgment is being made. Health inequality is a complex concept.⁸ For example, it can be expressed absolutely or relatively,^{9,10} which may influence our judgment regarding the magnitude, trend, and ethical and social significance of the difference. Clearly conveying this complexity requires more than a graphic display.

To consider appropriate captions when presenting health inequality, we consulted the numeracy literature in the field of health risk communication. This literature empirically investigates which verbal and numeric formats explain health risk information accurately and/or

encourage behavioral change. Using composite methods that include keyword searches, backward and forward citation searches, and snowball methods,^{21,23,27-40} we found 16 reviews published between 2000 and 2014. We identified common recommendations for verbal and numerical health risk communication for accuracy in these 16 reviews. We then derived 4 key considerations pertinent to verbal and numerical captions to accompany health inequality graphs.

Consideration 1: Decide Carefully From Whose Perspective to Describe Health Inequality

The framing effect is a well-known human behavior: persons change their answers depending on a favorable or unfavorable presentation of a logically equivalent situation.⁶⁸ In the context of risk communication, studies show that a presentation in terms of loss (eg, the operation has a 10% mortality rate) encourages risk-seeking choices, whereas a presentation in terms of gain (eg, the operation has a 90% survival rate) promotes risk-averse choices. The studies also suggest that the proportion of favorable and unfavorable narratives can influence perceptions of risk and treatment choices.^{21,28,30} In the context of health inequality, it may be important to consider from whose perspective we describe health inequality. Health inequality is a difference in health between at least two persons or groups. When there is a health inequality between two persons or groups, one person's (or group's) health is *worse or better* than another person's (or group's). We can extend this better-or-worse perspective to health inequality with more than two persons or groups, although it then becomes more complex. The better-or-worse perspective implies a norm with which to understand a health inequality, and it may influence our judgment about the magnitude and significance of a health inequality. Sometimes it may be preferable to describe health inequality from the perspectives of both better-off and worse-off.

Consideration 2: For Accuracy, Provide Numerical Rather Than Verbal Information

A difference in health can be expressed numerically (eg, a 10-year difference) and verbally (eg, a large difference). Because verbal representations

signal vagueness or uncertainty, numerical representation is preferred for accuracy.³⁰

Consideration 3: Reduce Calculations

Similar to the tenet that an effective graph requires a minimum amount of cognitive effort, a good verbal and numerical description is one that asks for the minimum number of inferences and calculations.^{28,36,38} In the context of health inequality, this means that the health level of each group in the graph should be specified and differences should be calculated and presented explicitly for the intended audience.

Consideration 4: Describe Health Inequality in Both Absolute and Relative Terms

A description of a health inequality should be expressed in both absolute and relative terms, for 3 reasons. First, the numeracy literature shows that the perceived reduction of risk is greater when the effect is presented using a relative term than when using an absolute term.^{27,28} When applying this finding to the health inequality context, our judgment of the significance of health inequality is likely to depend on whether it is presented as an absolute or a relative difference. Second, in his philosophical analysis of how we understand inequality, Larry Temkin argues that there is a good reason to assume that we contemplate both absolute and relative inequality when making judgments on the importance of inequality.⁸ Finally, in the health inequality literature, analysts commonly consider both absolute and relative inequality, because these 2 expressions of inequality can give contradictory results when we consider whether health inequality is increasing or decreasing or is larger or smaller in one population than another.^{9,10} Perceiving health inequality in both absolute and relative terms is thus important to our understanding of health inequality.

Another complication regarding absolute and relative inequality is that the same inequality can be expressed in relative terms in at least 4 ways (R. Cookson, email communication, January 2016). Consider the life expectancy of American women who are in the top 1% earning bracket for income distribution (89 years) versus American women in the bottom 1% earning bracket for income distribution (79 years).⁶⁹

The absolute inequality between them is 10 years ($= 89 \text{ years} - 79 \text{ years}$), while relative inequality can be 89% ($= 79 \text{ years} / 89 \text{ years} \times 100$), 11% ($= 100 - 79 \text{ years} / 89 \text{ years}$), 112% ($= 89 \text{ years} / 79 \text{ years} \times 100$), or 12% ($= 89 \text{ years} / 79 \text{ years} - 100$). Presenting all 4 is not a good option because doing so is likely to cause confusion, which is arguably more detrimental to understanding than the benefit of transparency. The literature offers little guidance as to which relative inequality should be presented and why, and decisions are typically arbitrary. Indeed, there is little recognition in the literature of the many ways of expressing relative inequality. Of the 4 possibilities of relative inequality in this example, relative inequality is either a big number (ie, 89% or 112%) or a small number (ie, 11% or 12%). To minimize the risk of superficially influencing the perception of inequality by the size of the presented number, we could present a pair of small- and big-number relative inequalities. The choice would be to pair either the 89% and 11% or the 112% and 12%. Any more pairs would require further explanation, which would increase the cognitive burden and even risk confusion.

In summary, a caption can provide a numerical (consideration 2), explicitly calculated (consideration 3) description of health inequality expressed in absolute and relative terms (consideration 4) from a carefully thought-out perspective (consideration 1). The following is an example of a caption for the aforementioned case of inequality in life expectancy among American women, incorporating these 4 considerations:

American women in the bottom 1% earning bracket for income distribution are expected to live for 79 years, and American women in the top 1% earning bracket for income distribution are expected to live for 89 years. This means that poor women will live 10 fewer years than rich women, and rich women will live 10 more years than poor women. The difference in their life expectancy is 10 years. To put it differently, the poor women's lives will be 89% of the rich women's lives, or the poor women's lives will be 11% shorter than the rich women's lives. This means that for every 100 years the rich women will live, the poor women will live for 89 years, or 11 fewer years.

It is possible that in order to remove any ambiguity based on the evidence supported by the relevant literature, this caption might, ironically, discourage its audience from reading it because of its length. The space for a caption is often limited as well. To find an appropriate balance between accuracy and length, future work needs to identify relative

importance of the preceding 4 considerations and the right amount of information given to the audience.

Discussion

Based on the literature on graph perception and numeracy, we offered important points to consider when creating effective graphs in the context of health inequality. We paid particular attention to the usefulness of dot charts for visually describing health inequality.

Our side-by-side comparisons of dot charts and bar charts emphasized the effectiveness, versatility, and flexibility of dot charts. We might wonder, then, why dot charts are so rarely used, especially given that Cleveland highlighted their effectiveness 30 years ago. We believe the answer lies in familiarity and convenience. For example, bar charts, but not dot charts, are included as a standard graph option in Excel, arguably the most widely used software package to create graphs. (For the Stata codes used to create the graphs presented in this article, see Appendix 1; and for other resources for drawing dot charts, see Appendix 2.)

Given the ubiquitous use of graphs in the health inequality literature, it is a loss to the field to overlook the vibrant multidisciplinary literature for direction on constructing effective graphs. In further exploring these rich literatures, however, we face two important challenges. First, because the literature on effective graphs is vast, it is difficult to synthesize all the developments regarding effective graphs. To select relevant articles to develop our considerations for visually representing quantitative data in Table 1, we used composite methods that included keyword searches, backward and forward citation searches, and snowball methods. Searching the literature on graphs comes with another methodological challenge. There is no indexing for graphs, requiring hand searches to identify papers with graphs. This is extremely time-consuming, if not impossible, to figure out systematically what types of graphs are used most frequently in the health inequality literature.

Second, it is difficult for effective graphs to keep up with the rapid developments in data and methods used in health inequality research. For this reason, the examples and focus of our article are deliberately simple. For example, most of the real-world examples of graphs we presented are cross-sectional. As health inequality research increasingly adopts life-course perspectives, much more attention should be paid

to how best to present longitudinal data. As we described, dot charts can accommodate longitudinal data, and more attention to the effective use of dot charts for longitudinal data is desirable. In addition, the measure of health used in our example of an appropriate explanation of graphs was life expectancy. As measures of health become more complex in health inequality research (eg, health-related quality of life), it will become more difficult to explain health inequality both verbally and numerically. Working from the basic foundation laid out in this article, future work needs to address these complexities, as well as the increasing preferences for fancier, interactive graphs. These challenges aside, graphs are a powerful tool to engage a wide range of audiences. It is our hope that this article will encourage health inequality researchers and policymakers to discuss further the effectiveness of graphs.

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Funding/Support: This study was supported by Nova Scotia Health Research Foundation Research Enterprise Development Initiatives (PSO-REDI-201-9737), Canadian Institutes of Health Research (MOP-142242), and the Primary Health Care Research Collaborative (CoR-PHC) at Dalhousie University. The funders had no role in our study design, data collection and analysis, decision to publish, or preparation of the manuscript.

Conflict of Interest Disclosures: All authors completed the ICMJE Form for Disclosure of Potential Conflicts of Interest. No conflicts were disclosed.

Acknowledgments: We gratefully acknowledge valuable guidance for review methods from Jill Hayden and Robin Parker. We would also like to thank

3 anonymous reviewers and Naomi Robbins for their helpful comments on an earlier version of this article. The views expressed in this article are the authors' and not the official position of the institution or the funder.

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Appendix 1

Stata Codes Written Using Stata 12 and Used to Create the Graphs Presented in This Article

Figure 1a

```
graph bar percent, over(Contract_type,
gap(0)) ylabel(,labels angle(horizontal)
value label nogrid) ytitle(Percent (%)) asyvar
bar(1, fcolor(black) fintensity(inten20)
lcolor(black) lwidth(medthin)) bar(2, fcolor(black)
fintensity(inten50) lcolor(black) lwidth(medthin))
bar(3, fcolor(black) fintensity(inten70)
lcolor(black) lwidth(medthin)) bar(4, fcolor(black)
fintensity(inten80) lcolor(black) lwidth(medthin))
bargap(100) outergap(*4.0) yline(0 5 10 15 20 25 30
35, lwidth(medthin) lpattern(dot) lcolor(black))
ylabel(0(5)35) graphregion(fcolor(white)
lcolor(white))
```

Figure 1b

```
graph bar Ave_pct_score, over(Income, gap(0))
asyvar bar(1, fcolor(black) fintensity(inten10)
lcolor(black) lwidth(medthin)) bar(2, fcolor(black)
fintensity(inten40) lcolor(black) lwidth(medthin))
bar(3, fcolor(black) fintensity(inten60)
lcolor(black) lwidth(medthin)) bar(4, fcolor(black)
fintensity(inten80) lcolor(black) lwidth(medthin))
bar(5, fcolor(black) fintensity(inten100)
lcolor(black) lwidth(medthin)) over(TestScore,
label(labcolor(black) angle(horizontal))
```

```

labsize(vsmall)) relabel( 1"School readiness
at 3" 2"Vocabulary at 3" 3"Vocabulary at
5" 4"Conduct problems" 5"Hyperactivity"))
yttitle(Percent (%)) yline(0 10 20 30 40 50 60 70
80, lwidth(medthin) lpattern(dot) lcolor(black))
ylabel(0(10)80, angle(horizontal)) legend(rows(1))
graphregion(fcolor(white) lcolor(white))

```

Figure 1c

```

graph bar years, over(Expected_years1, gap(0))
ylabel(,labels angle(horizontal) valuelabel nogrid)
asyvar bar(1, fcolor(black) fintensity(inten10)
lcolor(black) lwidth(medthin)) bar(2, fcolor(black)
fintensity(inten40) lcolor(black) lwidth(medthin))
bar(3, fcolor(black) fintensity(inten60)
lcolor(black) lwidth(medthin)) bar(4, fcolor(black)
fintensity(inten80)lcolor(black) lwidth(medthin))
over(population, relabel( 1"Total" 2"Women" 3"Men"
4"White" 5"Black")) yttitle(Years) yline(0 10 20
30 40 50 60 70 80, lwidth(medthin) lpattern(dot)
lcolor(black)) ylabel(0(10)80) legend(size(small))
graphregion(fcolor(white) lcolor(white))

```

Figure 2a

```

tway dot HUI_CAN Income, horizontal
dotextend(n) ylabel(1(1)2) yttitle("") ylabel(,
labels angle(horizontal) valuelabel nogrid)
xttitle(Health Utility Index) xscale(range(0.0 1.0))
xlabel(#10) xlabel(,format(%4.1f)) yscale(reverse
range(0 3)) msize(medium) mcolor(black)
graphregion(fcolor(white) lcolor(white))

```

Figure 2b

```

graph hbar huidhsi, over(hh_income, gap(50))
outergap(100) graphregion(fcolor(white)
lcolor(white)) yttitle(Health Utility Index)
yline(0 0.2 0.4 0.6 0.8 1.0, lwidth(medthin)
lpattern(dot) lcolor(black)) ylabel(0(0.1)1.0)
ylabel(,format(%4.1f)) ylabel(,labels

```

```

angle(horizontal) valuelabel nogrid) bar(1,
fcolor(black) fintensity(inten50) lcolor(black)
lwidth(medthin)) bar(2, fcolor(black)
fintensity(inten80) lcolor(black) lwidth(medthin))

```

Figure 3a

```

twoway dot percent Contract_type if sex == 1,
bgcolor(white) horizontal dotextend(n) ylabel(1(1)2,
nogrid labels notick angle(horizontal) valuelabel
noticks labsize(medium)) ylabel(1(1)4) ytitle('')
xtitle(Percent (%)) xscale(range(0 35)) xlabel(#10)
yscale(reverse range(0.5 4.5)) mcolor(black)
graphregion(fcolor(white) lcolor(white))

```

Figure 3b

```

twoway dot Ave_pct_score Income,
graphregion(fcolor(white) lcolor(white))
xsize(6) ysize(10) horizontal dotextend(n)
ylabel(1(1)5) ytitle(Income Quintiles)
ylabel(,labels angle(horizontal) valuelabel
nogrid) xtitle(Percent (%)) xscale(range(0 80))
xlabel(#10) yscale(reverse range(0 5))msize(medium)
mcolor(black) yscale(reverse) by(TestScore, note(.)
cols(1) graphregion(fcolor(white) lcolor(white)))

```

Figure 3c

For the graph 2000-2003

```

twoway dot years population, xsize(6) ysize(10)
horizontal dotextend(n) ylabel(1(1)5) ytitle("")
ylabel(, labels angle(horizontal) valuelabel
nogrid) xtitle(Years) xscale(range(0 80))
xlabel(#10) yscale(reverse range(1 5)) msize(medium)
mcolor(black) graphregion(fcolor(white)
lcolor(white)) by(, title(2000-2003, size(medsmall)
color(black)) graphregion(fcolor(white)
lcolor(white))) yscale(reverse) by(Expected_years1,
note(.) cols(1))

```

For the graph 2006-2007

```

tway dot years population, xsize(6) ysize(10)
horizontal dotextend(n) ylabel(1(1)5) ytitle("")
ylabel(, labels angle(horizontal) valuelabel
nogrid) xtitle(Years) xscale(range(0 80))
xlabel(#10) yscale(reverse range(1 5)) msize(medium)
mcolor(black) graphregion(fcolor(white)
lcolor(white)) by(, title(2006-2007, size(medsmall)
color(black)) graphregion(fcolor(white)
lcolor(white))) yscale(reverse) by(Expected_years1,
note(.) cols(1))

graph combine "/Users/Desktop/Figure 8
2000--2003.gph" "/Users/Desktop/Figure 8
2006--2007.gph", graphregion(fcolor(white)
lcolor(white))

```

Figure 4a

```

tway (dot HUI_CAN Income, horizontal ylabel(1(1)2)
ytitle("") ylabel(, labels angle(horizontal)
valuelabel nogrid) xtitle(Health Utility
Index) xscale(range(0.50 1.0)) xlabel(0.5 (.1)
1.0) yscale(reverse range(0 3)) msize(medium)
mcolor(black) graphregion(fcolor(white)
lcolor(white))) (rcap CI_lo_99_can CI_hi_99_can
Income, horizontal xscale(range(0.5 (.1)1.00))
xlabel(0.5 (.1) 1.0) xlabel(,format(%4.1f))
yscale(reverse range(0 3)) lcolor(black) legend(off)
graphregion(fcolor(white) lcolor(white)))

```

Figure 4b

```

tway (dot svy10 Income, horizontal mcolor(black))
(dot HUI_CAN Income, horizontal ylabel(1(1)2,
nogrid labels angle(horizontal) valuelabel
noticks ) ytitle("") yscale(reverse range(0
3)) ymtick(, nolabels noticks) mcolor(black)
msize(large)) (dot svy90 Income, horizontal
mcolor(black)) (, xtitle(Health Utility Index)

```

```
xscale(range(0.00 (.1)1.00)) xlabel(0.0 (.1)
1.0) xlabel(,format(%4.1f)) legend(off)
graphregion(fcolor(white) lcolor(white)))
```

Appendix 2

Software Resources to Draw Dot Charts

With Microsoft Excel

Peltier Tech Charts, <http://peltiertech.com/Utility30/>

With R

CTSpedia, <http://www.ctspedia.org/do/view/CTSpedia/Dotplot>
Examples

Jacoby WG,⁵⁵ [http://polisci.msu.edu/jacoby/icpsr/graphics/
manuscripts/Jacoby,%20Dotplots,%202006.pdf](http://polisci.msu.edu/jacoby/icpsr/graphics/manuscripts/Jacoby,%20Dotplots,%202006.pdf)