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Graphical Visions from William Playfair to John Tukey

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Abstract. This paper discusses the similarities and differences in Playfair and Tukey's visions of what graphically displaying quantitative phenomena can do now, and might do in the future. As part of this discussion we examine: (1) how fundamental graphic tools have become to the scientist, (2) three instances where modern views of graphics are unchanged since Playfair's time, and (3) one area where there has been a change. The paper concludes with a discussion of five important areas of current and future graphic concern.

Key words and phrases: Impact, elegance, grace, "Isthmus of Playfair."

1. INTRODUCTION

Modern physicists seldom cite Newton. This is not because his work is irrelevant, but rather because it is so ubiquitous that it is hard to imagine a world in which we did not know that $F = ma$. In the same way, Einstein's name is not always explicitly attached to $E = mc^2$.

Similarly, in graphics we use the work of Playfair and Tukey without citation—indeed often without knowledge of their contributions, because they are so basic to our understanding that we cannot easily imagine the world without them. This was brought home to me some years ago (Wainer, 1980) when I was reading a technical report that examined the *London Bills of Mortality* and their analysis by three early statisticians (Graunt, 1662; Arbuthnot, 1710; and Brakenridge, 1755). The aim of the paper (Zabell, 1976) was,

> to see how much these writers were able to extract from the *Bills* that we might reasonably expect them to—for example, how sensitive they were to questions of data quality, data consistency and data aggregation—we deliberately avoid the use of modern statistical methods . . . and limit ourselves to what is, in effect, a simple form of data analysis.

The result of these simple analyses was that a variety of errors were discovered that should have been seen by these early investigators, but were not. Zabell concluded that

> Although we have deliberately avoided all but the simplest of statistical tools, a remarkable amount of information can be extracted from the *Bills of Mortality*, much of it unappreciated at the time of their publication.

The "simple" methods of data analysis he used were graphical. Such data characteristics as clerical errors in the *Bills* literally stuck out like sore thumbs. Yet, Zabell's carefully researched work was flawed. In his desire to play eighteenth century scholar, using only techniques of analysis available at the time, he falls into an anachronism. The graphical method, on which his analysis leans so heavily, was developed after the scholars he discussed did their work.

The dating of the discovery of the line chart by the publication of Playfair's *Atlas* is problematic, but Zabell's finding of many obvious (if one uses line graphs) errors in the *London Bills of Mortality* indicates clearly that line graphs were not known at that time. This provides further support to Biderman's (1990) conjectures about Playfair's role in their development. Had Graunt, Petty or subsequent users of the *London Bills* graphed them as a Playfair time series the clerical errors would have stood out starkly, as would the historical fluctuations that Zabell noted.

The two papers that form the subject of this discussion help us in several ways. The first paper, by Costigan-Eaves and Macdonald-Ross, makes clearer just what Playfair's contribution was. Their discussion, along with the remaining details that will be in their upcoming monograph, provides important insights into what Playfair did, and why. John Tukey's paper on "Visual display in the decades to come" needs

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careful study. When John looks forward it is wise for the rest of us to think hard about what he tells us he has seen. Anyone who doubts this should reread his prescient "Future of Data Analysis" (Tukey, 1962) and reflect on what was discussed then and what has happened since. Although I fully understand that these were not independent events, neither are Tukey's remarks today independent of what will occur in future graphics.

2. PLAYFAIR AND TUKEY: THREE POINTS OF AGREEMENT

In the more than 200 years since the initial development of graphic techniques, we have acquired some wisdom in their use, born of experience. It is a telling measure of Playfair's accomplishment to note how many points of agreement there seem to be between Tukey and Playfair on important aspects of graphical display. Among these are the following postulates.

2.1 Impact Is Important

> Along with Playfair's desire to tell the story of history graphically was the desire to tell it dramatically.
>
> (Costigan-Eaves and Macdonald-Ross, 1990)

> The greatest possibilities of visual display lie in vividness and inescapability of the intended message.
>
> (Tukey, 1990)

Tukey's conclusion that impact is an important characteristic of a display seems to have developed, at least partially, in reaction to Tufte. Tufte's extreme view of the importance of maximizing the *data:ink ratio* (*data:pixel ratio* in modern parlance) has led many of us to reconsider the aesthetics of graphics. The Bauhaus axiom of "less is more" cannot be blindly applied in graphics, anymore than it can in architecture. Always one must consider other characteristics. Impact seems to be a key one. I suspect that Tufte is not as polemical as he would have us believe. Toward the end of his wonderful book, *The Visual Display of Quantitative Information* (Tufte, 1983, page 191), Tufte waffles. After stating a variety of what appear to be hard-and-fast principles, he states

> The principles [of graphics] should not be applied rigidly or in a peevish spirit; they are not mathematically or logically certain; and it is better to violate any principle than to place graceless or inelegant marks on paper.

Why should we concern ourselves with grace or elegance in our displays? If we are solely concerned with efficiency of information transmission, do such aesthetic principles matter? I have great sympathy toward the views expressed by Cleveland (1985), in which clarity and simplicity are guiding principles. Yet I note that nowhere in Cleveland's fine work are impact, grace or elegance ever mentioned. Perhaps this is why, though I admire the clarity with which many phenomena are uncovered in Cleveland's displays, I find none of them as memorable as Playfair's flawed "Balance of trade" plots, Marey's "overbusy" train schedule, or Minard's classic depiction of Napoleon's march into Russia. I believe that the message here is that although we need to pay attention to what we learn from experience and from careful experiments, we also need to heed the lore of graphic designers.

"Elegance and grace" are here used in a somewhat broader sense than the traditional mathematical meaning, which usually implies a kind of minimal leanness. This same sort of leanness is also used when describing the elegance of such minimal structures as suspension bridges. Yet we have learned that even rococo Victorian houses carry a grace and elegance on their own terms. Austerity may serve certain purposes, but humans often prefer, even require, more. Although I shudder to consider it, perhaps there is something to be learned from the success enjoyed by the multicolored, three-dimensional pie charts that clutter the pages of *USA Today*, *Time* and *Newsweek*. I sure hope not much.

2.2 Understanding Graphs Is Not Always Automatic

> . . . those who do not, at first sight, understand the manner of inspecting the Charts, will read, with attention the few lines of directions facing the first Chart, after which they will find all the difficulty entirely vanish, and as much information may be obtained in five minutes as would require whole days to imprint on the memory, in a lasting manner, by a table of figures.
>
> (Playfair, 1801, page xii)

> A picture may be worth a thousand words, but it may take a hundred words to do it.
>
> (Tukey, 1986)

There seems to be a widespread belief that a good graph should be entirely comprehensible without any instruction. Such a view is limiting. It seems to me that we can divide good graphs into at least two categories:

(i) A *strongly good graph* shows us everything we need to know just by looking at it.
(ii) A *weakly good graph* shows us everything we need to know just by looking at it, once we known how to look.

A good legend can transform a weakly good graph into a strongly good one. We ought to make this transformation when possible. I share Cleveland's belief (1985, page 57) that a legend should do more than merely label the components of the plot. Instead it should tell us what's important—what the point of the graph is. This serves two purposes. First, it informs the viewer, transforming what might be a weakly good graph into a strongly good one. But second, and of at least equal importance, it forces the grapher to think about why this graph is being prepared. Insisting on informative legends can substantially reduce the number of pointless graphs we see, and it will better structure the meaningful ones. This is because once a grapher is clear about what is the point of the graph, the appropriate way to structure it becomes clearer as well.

To illustrate this let me provide a sequence of plots which indicate a plausible path of development that a grapher might take. Figure 1 provides a rough duplicate of a plot that appeared in the 1964 Surgeon General's report *Smoking and Health.* The legend shown tells what the components of the graph are, but is not particularly informative. If the same graph were shown with a more informative legend, say

SMOKERS DIE SOONER THAN NONSMOKERS
Smoking Seems to Subtract about 7 Years from Life Expectancy

one could, puckishly, consider what the reaction to such a graph might be from defenders of the tobacco industry. I imagine that a statistician working in this industry who brought such a figure to his boss, as an example of clear data display, might be asked to rework the plot. The double Y-axis format is just the thing for obscuring these data. In Figure 2 is such a plot (worthy of the name) with a suitably informative legend.

2.3 A Graph Can Show Us Things Easily That Might Not Have Been Seen Otherwise

> I found the first rough draft gave me a better comprehension of the subject, than all that I had learnt from occasional reading, for half my lifetime.
>
> (Playfair, 1786)

> The greatest value of a graph is when it forces us to see what we never expected.
>
> (Tukey, 1977)

We have all had the experience of seeing something in a data set once we had graphed it that had lain hidden throughout many previous analyses. This is one reason that many of us have learned to start data analysis with graphics. There are too many examples of this to try to choose a "best" one, but one of my favorites grew out of Wald's work on armoring airplanes that was done during World War II (Mangel and Samaniego, 1984; Wainer, 1989; Wald, 1980).

Wald was trying to determine where to add extra armor to planes based upon the pattern of bullet holes

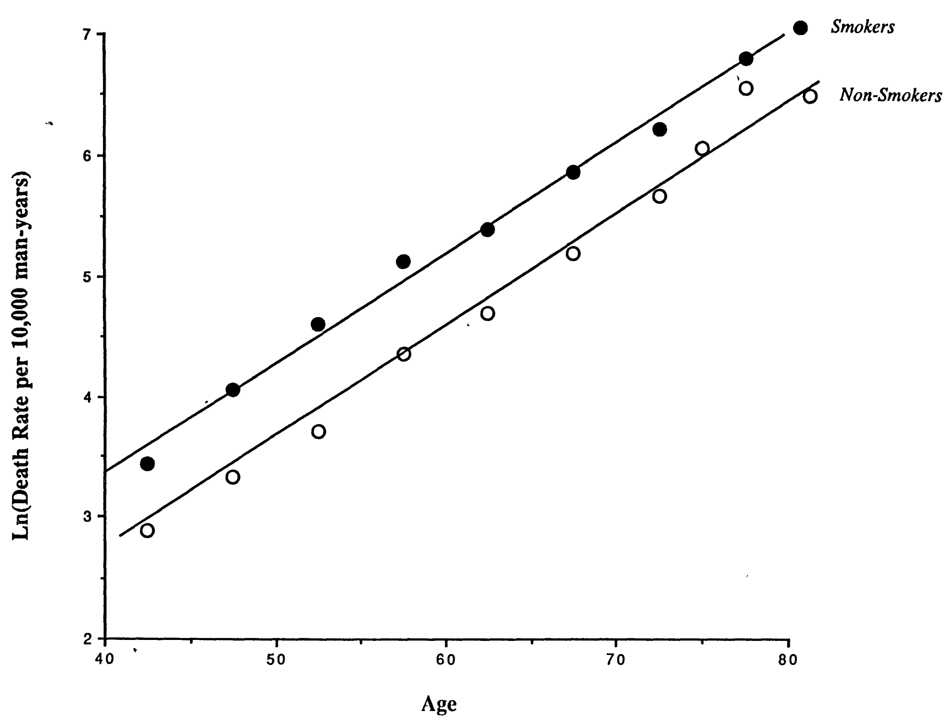


FIG. 1. *Death rate (log scale) plotted against age; prospective study of mortality in U.S. veterans. (Source: Surgeon General's* 1964 *Report, Figure* 1, *page* 88.)

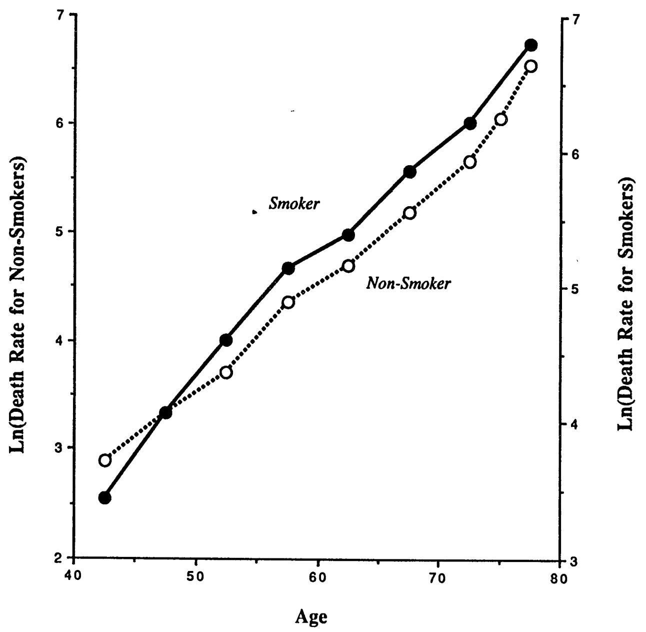


FIG. 2. *Surgeon General reports aging is the primary cause of death.*

in returning aircraft. His conclusion was to carefully determine where returning planes had been shot and put extra armor everyplace else!

This at first surprising conclusion becomes more reasonable when one considers the notion of nonignorable nonresponse. Wald made his discovery by drawing an outline of a plane (crudely shown in Figure 3) and then putting a mark on it where returning aircraft had been shot. Soon the entire plane had been covered with marks except for a few key areas. He concluded that since planes had probably been hit more-or-less uniformly those aircraft hit in the unmarked places had been unable to return and so those were the areas that required more armor.

3. ONE DIFFERENCE OF OPINION

In the 200+ years since Playfair first proposed graphics for conveying quantitative phenomena (using Tukey's important distinction), we have learned some things. Thus it isn't surprising that there are some areas of apparent disagreement between Playfair and Tukey. The fact that I had to look hard to find one says something about just how far we have come (or how far Playfair's work has taken us).

> Comparing with a curve—using a curve as a standard of comparison—is always poor graphics. We should do better.
>
> (Tukey, 1971, volume III, page 26-3)

This statement reflects a tenet of display with which I am in full agreement. For supporting evidence, consider the experiment done by Cleveland and McGill (1984), in which one is asked to judge the difference between two sharply up-turning curves.

It is impossible to see the peculiar differences between the two curves in Figure 4, which, when graphed explicitly (Figure 5) cannot be missed. Yet now we find, from two scholars whose study of the Playfair *corpus* is encyclopedic, that

> Playfair designed his curves in such a way that the reader is encouraged to focus on the *area* between the designated curves . . .
>
> (Costigan-Eaves and Macdonald-Ross, 1990)

Figure 6 is an accurate reproduction of a typical Playfair plot. We note from this how the negative balance of trade between England and the East Indies grew from 1700 to a peak at about 1730, and then

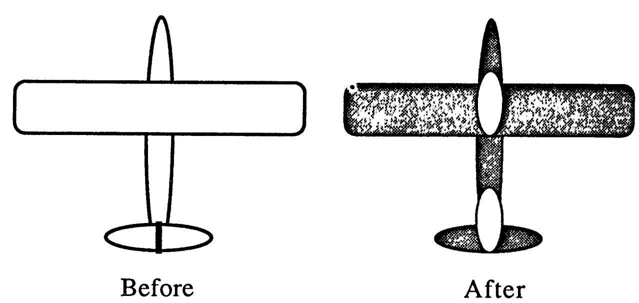


FIG. 3. *A graphical depiction of Wald's bullethole data.* (*Source*: *Wainer*, 1989, *Figure* 5.)

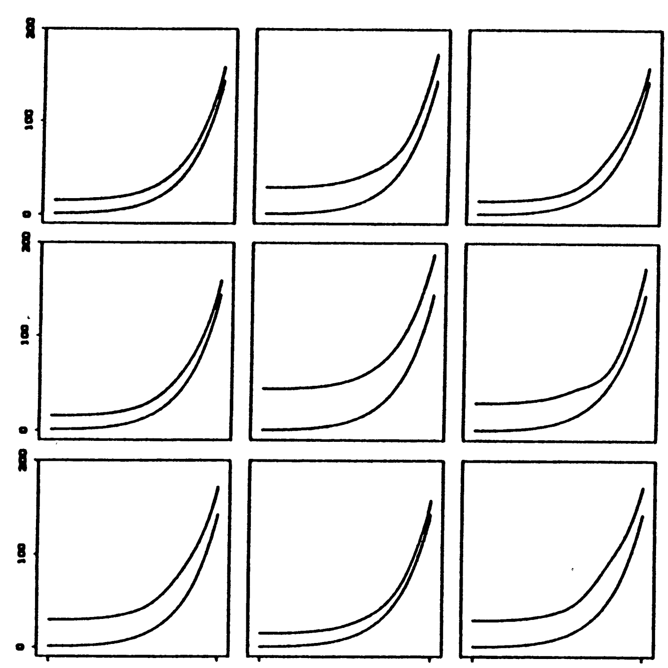


FIG. 4. *Curve-difference chart.* (*Source*: *Cleveland and McGill*, 1984, *Figure* 26.)

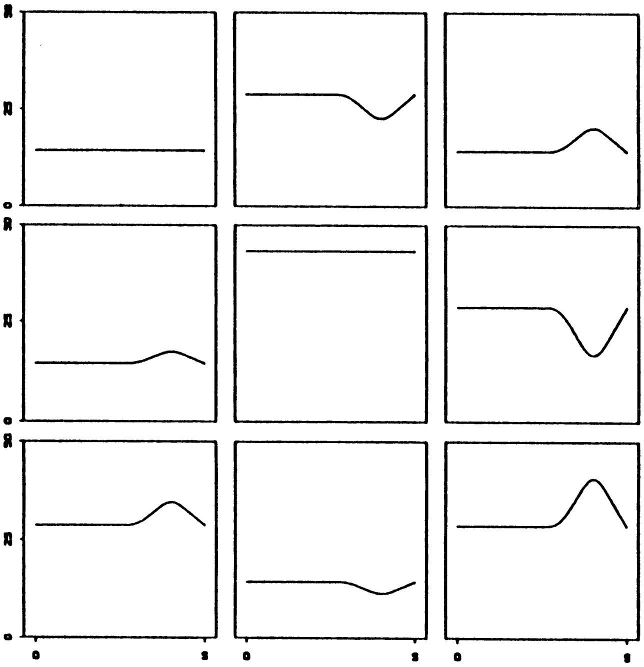


FIG. 5. *Curve differences.* (*Source*: *Cleveland and McGill*, 1984, *Figure* 27.)

tapered to a low around 1755. Then, after the "Isthmus of Playfair" it increased again through 1780. Is this so bad? What's so terrible about looking between two curves? I would call Figure 6 flawed only if we misperceive the data because of it. If the differences between the import and export curves are plotted explicitly we see (Figure 7) that we have missed the 1761 jump in the balance-of-trade deficit. Thus by violating Tukey's dictum (cited above), Playfair missed what he might have found.

4. SOME CONCLUDING THOUGHTS

So far, I have contented myself with selecting (and commenting on) three of the areas of agreement between Tukey and Playfair, and one area of disagreement. This tells us a bit about how much we have learned about data display since Playfair's day, or perhaps a little about how far into the future Playfair was able to look. It may be worthwhile at this juncture to emphasize what I feel are key aspects of Tukey's vision of the future (and one question that remains in my mind).

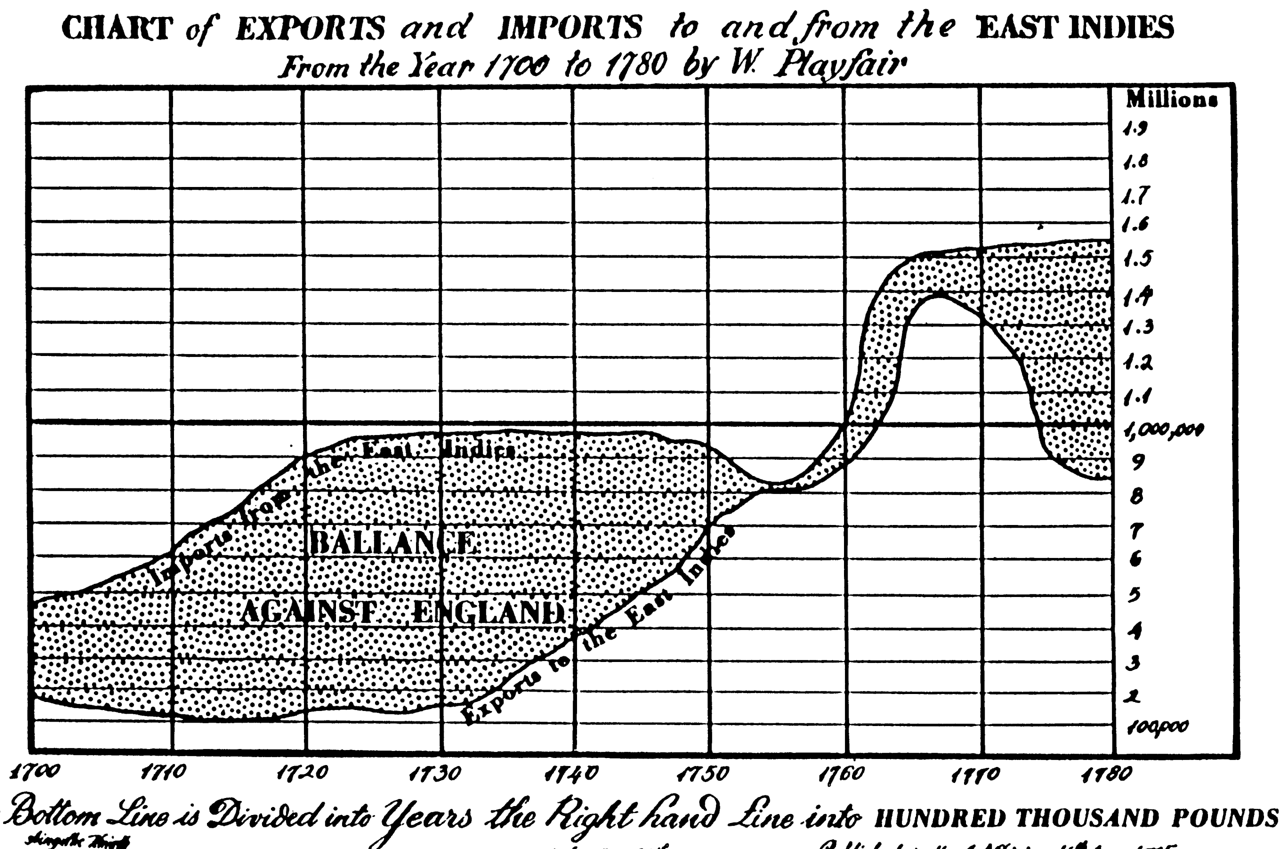


FIG. 6. *Curve-difference chart after Playfair.* (*Source*: *Cleveland and McGill*, 1984, *Figure* 6.)

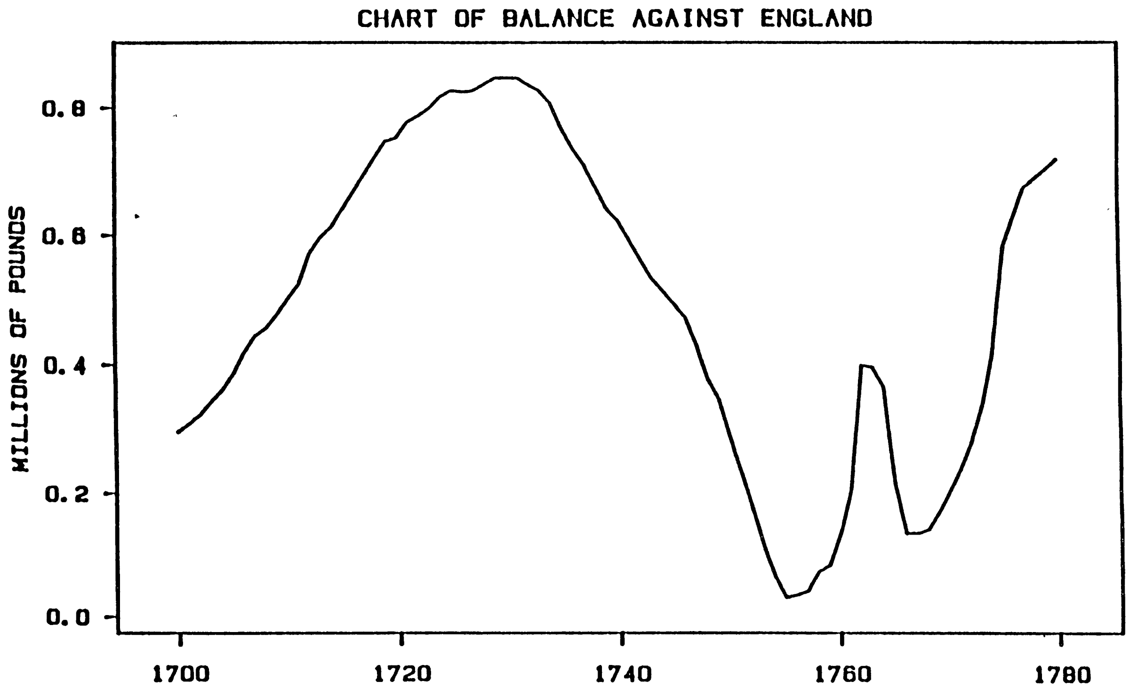


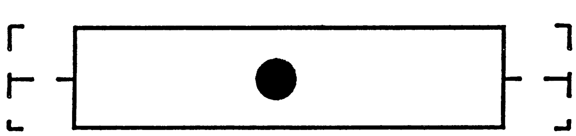
FIG. 7. *Playfair data.* (*Source: Cleveland and McGill,* 1984, *Figure* 28.)

4.1 "The purpose of display is comparison, not numbers."

How does this jibe with Tukey's use of multiple, stacked column charts? When we compare medians these seem to work fine. But when we are comparing lengths (whisker lengths, between-hinge lengths, etc.) we are starting from different bases, and the stacked columns approach appears to violate the principle of making comparisons only with straight lines, discussed in Section 3.

Yet the plot we use depends upon what we want to look at. Plotting is not done in isolation. It is usually done in sequence, as a part of an investigation. Thus stacked column charts are useful for certain things, less so for others.

As an example, we might ask what do box-and-whisker plots obscure, which might be better displayed with stacked column charts? I showed the box-and-whisker plot below to a variety of statistically skilled colleagues and asked what were the outstanding features of the data that this depicted. The most common responses were "*symmetric*" and "*short tails.*" No one mentioned the most curious aspect of this data set: *bimodality.*



Once suggested, the bimodality is obvious. How else could we squeeze 25% of the data into such short whiskers? If these data had been plotted by hand, or in the obvious order of a hand analysis (stem-and-leaf diagram first), the bimodality would have been clear. If this step was omitted, by some step-hiding graphical data analysis algorithm, we might have missed it. Of course, Tukey's stacked versions would have told us this part of the story clearly.

4.2 Emphasizing some of Tukey's points

Penultimately, I would like to emphasize, with commentary, some of Tukey's other main points. Five that I found of special value are the following.

1. " . . . *We badly need a detailed understanding of purpose.*" In graphics (as in anything else), before we begin to do anything, we need to know why we're doing it. Different kinds of displays are used for exploratory purposes ("prospecting") than for communicative ("transfer") ones. It is important that we form a hierarchy of purpose and don't try to do too much; for in so doing we will often degrade the display for our primary purpose.

2. "*The questions that visual display answers best are phenomenological.*" Graphic display can allow the eye to move from the leaf, to the branch, to the tree, to the forest, and back again. Other procedures aid us in some of these, but none are so general, nor so quick. It is a waste to utilize such power to merely store data.

"'Reading off numbers' is *NOT* the point of a graphic. If we want numbers, we can do better by ... going to a conventional table." This needs to be kept in mind for "the planning and conduct [of graphical experiments] needs to reflect what we think of as the most important broad purposes of visual display." Much graphical experimentation (including my own unfortunate forays) has focused on the wrong thing. Perhaps following Tukey's outline might help; at least it starts out in the right direction.

3. "*The absence of phenomena is itself a phenomenon.*" This is especially cogent to those of us interested in assessing the effects of missing data. Remembering this is what made Wald's (1980) model for airplane armoring so compelling, as well as Holmes' solution to the baffling mystery of the murder surrounding the theft of Silver Blaze.

4. "*There can be no substitute for* ***computation as a support for display***." Note the emphasis. Results are meant for the human eye and the human mind. We ought to consider seriously how best to get them in there. How long gone the notion of a nomograph, in which the display is in the service of the computation.

5. "*Color is a disappointment.*" So far, the availability of color has usually only provided one more parameter to be misused. Aside from aiding in emphasis ("consider the red points") there seem to be few useful applications of color. Certainly the number of instances where it has truly helped is dwarfed by the number where it provides nothing, or worse, misleads.

4.3 Finishing up

Graphical display is something that is so close to us that it is easy to lose touch with the fact that it is an evolving invention. Remember Zabell's analysis. A great deal is known about display, but there is much that is still shrouded. Progress is best made if we learn what is known and begin from there. The two papers presented today go a long way toward helping us understand both past accomplishments and future challenges.

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