# The Mathematical Life of Florence Nightingale

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## Introduction

The story of Florence Nightingale has gone down in popular legend. The Lady with the Lamp, the "ministering angel" of the Crimea, she worked tirelessly to reform the way hospitals were run, to professionalise nursing and to improve public health by campaigning for sanitation legislation. She became an idol even in her own lifetime, and more than a century after her work in the Crimean war shot her to fame, children were reading books like the Ladybird book on Florence Nightingale, which I remember owning (along with one about Nelson and one about Elizabeth I). It told an inspiring story of how young Florence loved playing hospitals with her dolls, and how this led to her growing up to revolutionise nursing, in spite of the strong resistance of certain members of the medical profession who didn't think a mere female doing (to their minds) a bit of nursing as a hobby should be telling them what to do. These sorts of portrayals are all very well, but they totally miss the most important question: how did she manage to effect the changes she did? The answer is that she made her argument so compelling that it was impossible to ignore, and she did it with statistics – and in particular with the innovative use of statistical diagrams that illuminated the data in a way tables of figures just cannot achieve.

Today I want to explore the mathematical work of Florence Nightingale. How she came to do it, how it fits in with the development of statistics as a mathematical subject, and the use of statistical charts in general, in the 18th and 19th centuries, and how her approach to data still has lessons for us today. Along the way we'll be counting all the animals at the zoo, weighing a mountain, and sabotaging the French economy (sorry France).

## Who was Florence Nightingale?

Florence Nightingale was born into a wealthy family, on May 12th 1820. Her parents were William and Fanny Nightingale, and she had an older sister. Both girls were named for their places of birth – Florence's sister was born in Naples, though, so the parents instead used the old Greek name for that city: Parthenope. The family mixed with the great and the good, and the girls were friends with another young lady who would become known for mathematical contributions: Ada Lovelace. Florence was an extremely intelligent and eloquent child, with, right from the start, an interest in numbers, data, and making sense of them. The 8-year old Florence wrote a detailed letter to her grandmother about a trip to the zoo which listed not only all the animals she had seen but exactly how many of each animal there were: *Dear Grandmama. The baby is pretty. I have been to the Zoological Society twice. There are 2 leopards, 2 bears, 2 parrots, 2 emeus (which are very large birds).2 rabbits. 1 lion, 2 cockaatoos, 3 squirrells, 4 kanguroos, 6 monkies, (3 in a cage, 3 chained to a pole with a little house at the top). 1 rattel, (a very fierce creature). several Esquimaux dogs, Captain's Parry's Esquimaux dog, 1 guinea pig, 1 Costi Monti, 3 lamas, (1 brown one, 1 white one, & a small brown one), & other creatures that I forget the name of.* Very cute. Another letter, this time to Parthenope, had tables of data about the distribution of fruit and vegetables in the family pantry.

The expectation for a young woman of Nightingale's social class was to marry and have a family. But this was not what she wanted: after spending some time volunteering at a hospital in Germany, she decided that nursing was for her. Her parents were vehemently against this – it was in their view an entirely inappropriate pursuit for a wealthy and respectable lady. But Florence prevailed. In April 1853 she became superintendent of a hospital, the "Institute for Gentlewomen during Illness", at 1 Harley Street in London.

The pivotal moment in her life was the Crimean War (5 October 1853 – 30 March 1856), which was fought between Russia and an alliance which included the Ottoman Empire, Britain, and France; the British joined in at the end of March 1854. It was perhaps the first war where reporting became an impetus for change. Newspapers were able very quickly to report on conditions for the soldiers, which were appalling, and the pressure to address the shocking situation was impossible for the authorities to ignore. Florence Nightingale had become friends with Sidney Herbert, the War Secretary. He supported her plan to take a group of nurses (38 in total) to the Crimea to work in the military hospitals, the first time women had been permitted to serve in an official capacity. They arrived on November 2nd 1854. The hospitals were filthy. There was no real sanitation, no ventilation, no proper facilities for washing, not even the most basic plumbing: there were even overflowing sewers. There were accounts of dead dogs, even dead horses, being left to rot in the street for weeks, right next to hospital wards. There were rats running about under the beds, and for around 2000 soldiers at the hospital in Scutari, the worst one in terms of sanitation, there were no basins for washing, and only 14 baths. Far more soldiers died from what we now know are preventable diseases than from actual injuries sustained during battle. Nightingale set to work immediately to improve things, and the reforms she pushed for certainly saved thousands of lives. She returned from Crimea a celebrity and spent the rest of her life campaigning, with huge success, for improvements in the way hospitals were run, both military and civilian hospitals, for sanitation reform more generally, and for the professionalization of nursing, with nurses receiving proper training and qualifications.

It's amazing to our modern ears, but as Nightingale expert Hugh Small has pointed out, it wasn't the fact that lots of soldiers were dying from disease rather than wounds that was the surprise to the Victorians, after all at that time things like typhus and cholera were killing huge numbers of civilians as well. The surprise was that something could be done about it. If you think these diseases are caused by "bad air", there's not much to be done. This was before the germ theory of disease after all, so it wasn't obvious that things like washing your hands could make a difference. That was the case that Florence Nightingale needed to make.

When back in England, she wrote a detailed report (*Notes on Matters Affecting the Health, Efficiency, and Hospital Administration of the British Army*, 1858), a shorter pamphlet called *Mortality of the British Army, At Home, At Home and Abroad, and During the Russian War, As Compared with the Mortality of the Civil Population in England* (1858), and she also joined forces with the social reformer Harriet Martineau to spread the word about her work, in an 1859 publication called *England and Her Soldiers*. And Florence Nightingale made her arguments with data. Her approach is characterized by three very important qualities, which I'll elaborate on during this talk. Firstly, an insistence on good quality data. Second, an understanding of what the data is saying, and what it is not. And third, a brilliant knack of showing this to people using compelling visual interpretations. We'll begin with a brief look at what else was going on in terms of data and statistics in the 19th century.

## A brief history of early statistics

The origins of the word "statistics" tell us something about its history. It comes into English probably from the German word Statistik, or roughly "science of the state" (there's also an earlier Italian word statista meaning someone concerned with matters of the state). People have been counting populations for thousands of years – Jesus was born in Bethlehem because of a census, after all, and the Domesday Book of 1086 was an inventory of all the property and livestock in England. We start to get calculations of imports and exports, national wealth, the change in prices and wages over time. These used to be called "political arithmetic" in English. The first use of the word "statistics" in English is thought to be in John Sinclair's 1791 *Statistical Account of Scotland*, which among other things aimed to measure what he called the "quantum of happiness" of Scottish people. Data to do with people (like life expectancy, marriage and divorce rates, and so on) came to be known as "vital statistics" in 19th century Britain. There was controversy even about gathering fundamental information like the population of England. We've had a census every ten years since 1801, but opponents of that first census worried that it would give encouragement to our enemies if it showed a smaller population than we'd been claiming. It wasn't until 1836 that it became compulsory to register births, marriages and deaths in England and Wales.

In France in the 1820s and 1830s, the study of so-called "moral statistics" was emerging. These are statistics on things like crime, divorce, prostitution. The French lawyer and proto-statistician André-Michel Guerry produced his *Essay on moral statistics of France* in 1833 – we'll meet him again later when we talk about diagrams. Gradually, ideas from probability, like averages, started to be incorporated. People like the Belgian astronomer, mathematician, and sociologist Adolphe Quetelet began looking seriously at statistics about populations, beyond just counting them; there began to be calculations of things like the average number of deaths from different causes in different populations. Quetelet studied statistics about the human body and introduced the idea of the "average man", looking at characteristics like height that follow a normal distribution (he also invented what's now called the Body Mass Index). Nightingale was familiar with his work and even met Quetelet in 1860. Unfortunately, there were some who took these ideas down a very dark path, and believed it would be possible to scientifically measure things like propensity to criminality, or "prove" different levels of intelligence in different ethnic groups. This entirely discredited idea, which gave itself the scientific seeming name of eugenics, is a stain on the history of statistics.

The idea of using averages of data was not itself new – scientists had been using them for some time in things like astronomy, where you take several readings, each likely to be slightly inaccurate due to imperfections in equipment and so on, but then by taking the mean of the readings you expect to get a more accurate result. This is a sensible idea assuming the errors are random. But when it comes to averaging things like crime rates, it was surprisingly controversial. The issue is that if you are trying to (say) measure the position of Venus, there is an exact correct answer that you are trying to find. But this isn't true of population data – there's no "right" answer for the birth rate, or the number of people who'll get married, or die, or commit a crime, in a given year. And if we believe in free will, how can we also believe we can predict the outcomes of a million personal choices? Such ideas were troubling. Charles Dickens, for example, wrote that if the number of people killed so far this year is below the annual average, "is it not dreadful to think that before the last day of the year some forty or fifty persons must be killed - and killed they will be." On the other hand, George Eliot was fascinated by statistics. There's a passage in her novel Daniel Deronda, which I suspect reflects her views, and certainly is similar to the approach of people like Quetelet: "we knew well enough before counting that in the same state of society the same sort of things would happen, and it was no more wonder that quantities should remain the same than that qualities should remain the same, for in relation to society numbers are qualities - the number of drunkards is a quality in society - the numbers are an index to the qualities, and give us no instruction, only setting us to consider the causes of difference between social states."

It's this last part that's the key: if we have the information we can then think about why there are differences in different settings, and that can help us improve things. But before we can do anything we need data, and we need it to be good quality data. This is the first thing that Nightingale did really well.

## The importance of good data

There are some really common pitfalls we can fall into with data, and Florence Nightingale was quick to notice them. For example, she campaigned to put nursing on a professional footing, and for nurses to be trained. But critics said there was a higher chance of dying under the care of a trained nurse than an untrained one! How can this be? The issue is the underlying population. If you have a hospital with trained nurses and untrained ones, how are you going to allocate patients? What was happening was that the trained nurses were being assigned to the sickest patients, who quite naturally have the highest chance of dying, whoever they're being looked after by. This is a huge pitfall: not comparing like with like. In medicine, the average survival rates for different groups undergoing medical procedures are nowadays properly considered when assessing performance of surgeons.

The failure to understand difference in underlying populations is unfortunately still with us. These kinds of misunderstandings continue to have serious consequences for policy decisions. Consider Boris Johnson's reported October 2020 "joke" on WhatsApp: "I must say I have been rocked by some of the data on Covid fatalities. The median age is 82 – 81 for men, 85 for women. That is above life expectancy. So, get Covid and live longer.[1]" The problem here is he's comparing with life expectancy at birth, which is an average that includes all the people who die young from accidents or other causes. A median of 85 means half of all women will live to 85. But a woman of 85 in the UK has a median life expectancy of 92, according to government data. A man of 81 has a median life expectancy of 89. If only senior politicians were as aware of the importance of understanding data as Florence Nightingale. It's been estimated by the Health Foundation that each person who died of Covid in the UK lost on average 10 years of life.

Here's another example. When looking at causes of mortality in military hospitals, Florence Nightingale realized that information was only being gathered once a week. This meant that many deaths were going

[1] Reported in https://www.theguardian.com/theobserver/commentisfree/2021/jul/24/get-covid-and-live-longer-no-it-doesnt-work-like-that

entirely unrecorded, because anyone admitted to hospital between census dates who died before the next census was completely missed by the figures. A weekly census underestimates the amount of illnesses of short duration, and that skews the data. Florence Nightingale was insistent about the need for daily data gathering and of course that's what we now do. In this case, the error is not noticing our systematic omissions. There's a popular meme that illustrates this well – patterns of damage on aircraft returning from missions over enemy territory show particular "hotspots" of damage. Should we reinforce those areas of the aircraft as they are most likely to be hit? Well, no, because these are aircraft that have returned – we are missing the ones who haven't returned because the places they were hit caused the plane to crash. What this really shows is the places you can be hit and survive. If anything, you should reinforce the other parts of the plane. Nightingale also noticed many other issues and inconsistencies – sometimes inhabitants of the places fighting was taking place were counted in army hospital data, sometimes not, for instance. This makes it impossible to do analyses over time. It's absolutely vital to have data as accurate and consistent as we can get it. This was a key part of Nightingale's work, in collaboration with other statisticians of the time like William Farr.

## Interpreting the numbers

When you have at last got robust data, you next have to know how to interpret it. Florence Nightingale was irate to find a government official, Lord William Paulet, boasting in an April 1855 letter that the numbers dying in military hospitals had "very much diminished". This was true, but the issue, as she pointed out, is that the number of deaths having decreased is meaningless without knowing the total hospital numbers. In this case, the number of deaths had gone down, but the number of patients had gone down even more, so in fact mortality rates had increased! It's a "what's the denominator of this fraction" issue. Medical statistics doesn't make this kind of error any more (I hope) but it's surprisingly common for similar mistakes to be made in the media and elsewhere.

Two typical media stories are the puff piece for a new sport or hobby, and the latest food found to be killing us all. You know the kind of thing – underwater darts is the fastest growing sport in the UK, we're told. What they don't mention is that this means a bloke called Bob invented underwater darts, and has now got two friends to join him, resulting in the headline – true but misleading – claim that numbers have trebled. What about food: is bacon killing us? Well, it's been found that eating a lot of bacon (two rashers every single day your whole life) increases your risk of getting bowel cancer by a factor of 18%. But the crucial question is: from what baseline? On average, there's about a 6% chance of getting bowel cancer at some point in your life. Increasing that by 18% brings it up to 7%. It's not nothing, but compared to the risk of something like smoking, it's tiny. Smoking increases your risk of lung cancer by over 2000%, you're more than twenty times as likely to get lung cancer if you smoke than if you don't.

The lesson in all this is simple: raw numbers tell you nothing without context! So, next time you are faced with a statistical claim ask: what would Florence Nightingale do?

## A picture is worth a thousand words

The most important thing that Florence Nightingale did, when she had her data and she knew what it was telling her, was to communicate this information through the inspired use of statistical diagrams, and to use those to argue compellingly for change. This really was ground-breaking. The use of charts of any kind, even the drawing of graphs, was a relatively new phenomenon. She wasn't the first person to represent statistics visually, but Florence Nightingale had a knack for choosing pictorial representations that instantly got the message across, and the results were powerful. I'm going give you a brief guided tour of some landmark visualizations of data preceding Nightingale, then talk you through her most famous infographic, and show you why I think it's so successful. Finally, we'll look at a few other examples of her statistical diagrams.

One example of a really great idea for making the information come alive is also a very simple one – on a map where you are recording measurements of some physical characteristic as it varies by location, join the points where the values are the same. My favourite example of this is by the English mathematician Charles Hutton. He was part of an experiment in 1774 to try and discover the mass of the Earth. First, you have to weigh a mountain! Then you find its volume, and hence its density. We use this as an estimate for the density of the whole planet, whose volume, being roughly a sphere, we can also calculate. The two combined give us the mass of the Earth. Weighing the mountain was done by measuring very tiny fluctuations in pendulums – near the large mass of the mountain they don't hang quite vertically but are pulled slightly in the direction of the mountain. By measuring these small deviations from vertical, you can measure the mass of the mountain. The mountain chosen was one in Scotland, Schiehallion, that's quite isolated from other large masses. The other reason for the choice was that it's a rather symmetrical mountain. When it came to measuring the volume, Charles Hutton surveyed the mountain and made a map which was, it's believed, the first one to use what we now call contour lines, joining points of the same height. By doing this he could then approximate the mountain by a series of slices, and work out the volume that way. Joining points of equal value for some statistic had been done previously by various people for "isobath" lines – joining points of equal depth underwater, and by Edmond Halley "isogons", or "Halleyan lines" to show lines of equal magnetic variation. But Hutton's contour lines are my favourite.

Charts that show information about statistical data really only start to appear in the late 18th and early 19th century, and in Britain at least they took a while to catch on. One reason for this was the colourful reputation of an early innovator, William Playfair. William Playfair (not to be confused with his brother John Playfair, whose alternative formulation of Euclid's fifth postulate is probably the one we all learned at school, and is known as Playfair's axiom) was a Scottish engineer, political economist, sometime spy and occasional lawbreaker. Actually, the Wikipedia article about him lists an even longer catalogue of careers: millwright, engineer, draftsman, accountant, inventor, silversmith, merchant, investment broker, economist, statistician, pamphleteer, translator, publicist, land speculator, convict, banker, ardent royalist, editor, blackmailer, and journalist. Playfair produced many books and pamphlets with financial and economic statistics, such as his 1786 *Commercial and Political Atlas*, and invented charts we still use today.

At the time, there was a very popular biographical timeline that had been created by Joseph Priestley (discoverer of oxygen), in which lifetimes were represented by bars. Inspired by this, Playfair had the idea of representing numerical information with bars, and that's how he came up with the bar chart. There's an example in his *Atlas* called *Exports and Imports of Scotland to and from different parts for one Year from Christmas 1780 to Christmas 1781.* (Was his the first bar chart? There's a case to be made that Nicolas Oresme produced something like a bar chart in the 14th century but it was in a completely different context and I'd bet good money Playfair had never seen the manuscript in question. However, while writing this I've come across a claim that there was an earlier bar chart showing low and high-water marks of the Seine for each year between 1732 and 1766, that appeared in a book called *Cartes et tables de la géographie physique ou naturelle* in around 1770. I'll need to investigate further!)

Another one of Playfair's charts, from 1821 or 1822 (I've seen both stated), combines bars with a line graph: it shows the "weekly wages of a good mechanic" along with the price of "a quarter of wheat", over time, which he says illustrates that, at the time he was writing, "that never at any former period was wheat so cheap, in proportion to mechanical labour as it is at the present time". It would be just a short step from that to the kind of thing we would now do, which is essentially to divide wages by prices, and plot something like how many quarters of wheat a "good mechanic" could buy with their week's pay. The novelty of these graphical representations is evidenced by the fact that he had to explain and justify what he was doing. "This method," he says, "has struck several persons as fallacious, because geometrical measurement has not any relation to money or time; yet here it is made to represent both".

In his 1801 *Statistical Breviary*, Playfair introduced pie charts, and he does seem to be the first, at least that I've found, to have done this. For example, there's one showing the "proportions of the Turkish Empire located in Asia, Europe and Africa before 1789", but the conventions haven't entirely been set up yet – some of the charts show concentric circles rather than the circle cut into slices. It took a while for the "pie chart" to be standardized (by the way, when they reached France, where they were enthusiastically adopted years before they properly took off in Britain, pie charts were nicknamed *Camemberts*). Playfair's reputation in Britain suffered when he was convicted of libel and imprisoned for debt. In France he took part in the storming of the Bastille, but the French may have thought less of him if they had known he was a secret agent for Britain who proposed and carried out a massive, and successful, operation to devalue the French currency by introducing thousands of fake "assignats" into circulation.

The use of statistical diagrams was, for whatever reason, taken up sooner in France than in England. André-Michel Guerry, whom we mentioned earlier, used a variety of charts and graphs in his work. In his 1833 *Essai sur la Staistique Morale de la France*, he put together huge amounts of data on crimes, literacy, suicides, all under the umbrella of "moral statistics". He illustrated data for the different regions of France in six detailed maps, showing that, for example, the crime rate cannot be an unchangeable property of all human, or even all French, society, if it can vary so much by region. Meanwhile Charles Minard was producing charts including an 1858 map with pie charts for each region representing the total amount (given by the size of the pie), and the types, of meat brought from the regions for consumption in Paris.

Finally, speaking of maps, there's one incredibly famous map we should mention because it relates to exactly the kind of argument Nightingale was about to make. It was at the same time as the Crimean War that John Snow produced his famous cholera map in 1854, showing that a particular outbreak of cholera in Soho in London was clustered around a water pump in Broad Street (now called Broadwick Street). When the authorities removed the handle of the pump, making it impossible to use, case numbers dropped dramatically. That was strong evidence that cholera was caused by polluted water rather than "bad air".

## Florence Nightingale's Diagrams

Now let's see how Florence Nightingale fits into this story. After she came home from the Crimea she was evangelical about reporting what had happened and how improvements in sanitation had transformed the situation. She wanted to ensure that these changes would be adopted universally. So: how to convince. The official data were often inadequate and the vital information was hard to see in the pages and pages of dry statistical tables. So, the question for Nightingale was how best to represent the information. Let's look more closely at her most famous chart: the so-called polar area chart representing mortality in the army.

Playfair's pie charts and his other circular graphs are one way of representing data but the pie chart shows you proportions of a fixed whole – literally slices of a pie, so this isn't going to be a good way to show how proportions change over time (you'd have to do a pie chart for every month to get the same information across). What the polar area diagram does is to show in a very clear way this information as it changes over the year, with the advantage that we are quite used to associating time with circles: clocks, which after all are just circles divided into twelve, are all around us. So, putting the months of a year around a circle with their data feels very natural. For each month, there are regions representing the deaths from wounds, the deaths from "zymotic" or contagious diseases, and the deaths from other diseases. The circle on the right shows Year 1, starting in April, and the circle on the left Year 2. Obviously, we can see something dramatic happens in Year 2.

I want to show you how exactly the relevant size regions are produced. These are area diagrams, which means that amount you want to represent is proportional to the area of the given region. First, Nightingale took the known data for deaths in a given month, as well as the total size of the army at that time. For a toy example, let's say in a given month there were 40,000 men in the army, that 400 men died of wounds, 800 of preventable diseases, and 200 of other causes. Then deaths per thousand men would be 10 of wounds, 20 of preventable diseases, 5 of other causes. It's important to calculate the mortality rates not just the numbers (and this was something the official data hadn't been doing before Nightingale) because otherwise you can't distinguish between deaths decreasing because you've improved hospitals, or just because there are fewer people left to kill. Finally, Nightingale calculated how many deaths per thousand men there would be over the whole year, if that month's death rate persisted, by simply multiplying by 12. So, the annualized deaths per 1000 men in our case would be 120 of wounds, 240 of preventable diseases, 60 of other causes. When you have your annualized death rates for each month, you can then plot them around a circle, using a suitable scale. In our case, with the 120, 240, 60, we want wedges whose areas are in those proportions. The area of a wedge of radius $r$ is $\frac{\pi}{12}r^2$. If our radius representing a death rate of 60 is say 1cm, then doubling the radius gives an area of four times the original wedge, so a wedge with radius 2cm corresponds to the "240" death rate. For our 120 figure we'd need a radius of $\sqrt{2}$cm.

Now, this toy example looks a bit unrealistic: with 800 of the 40,000 dying each month, it would mean 240 of every thousand, or nearly a quarter of the army, dying each year of preventable diseases. But actually, it was so much worse than that that sometimes it led to crazy sounding numbers, for instance there was one month, January 1855, where out of an army of 32,393 men, 2761 died of preventable diseases, this is $\frac{2761}{32.393} = 85.234$ men in every 1000, which over the year would mean of 1022.8 of every 1000 men would die of preventable diseases. This sounds like it must be wrong, but it is possible when we remember that when people die they are replaced. So, you could have an army of 40,000 and still have 50,000 deaths over a year. Fortunately, after the Sanitary Commission finally arrived in late March 1855, death rates from preventable diseases plummeted, and Nightingale's graph shows this brilliantly.

The graph did not cause the clean-up in Crimea; it was produced later. What it did was to give such compelling evidence of their efficacy that it led to permanent reform. We can see that a huge proportion of deaths were preventable by improving sanitation. Mortality rates at the Scutari hospital dropped from over 41% to around 2%. It doesn't tell us for sure that absolute numbers of deaths came down, though they did, because we don't know the size of the army from this diagram, but that's not what matters.

I have to tell you that, contrary to popular belief, Nightingale did not invent polar area graphs. That honour probably goes to Guerry, not in his most famous book but in a lesser-known 1829 paper looking mainly at meteorology, but that also graphs the relationship between death rates and time of day. It contains six polar area charts. Four of them show how much of the time the wind was blowing in each of eight directions over each quarter of the year; two show numbers of deaths for each hour of the day. They don't really tell any story – they aren't a call to action in the way hers were. But they are likely the first ones ever printed.

Let's look at a couple of other diagrams that Florence Nightingale used. First, her "batwing" chart also shows the dramatic effect of the sanitation commission. Here, it is not the areas but the length of the radial lines that are in proportion to the mortality rates, and then these points have been plotted in a graph. This gives a very strong visual impression! I'm not aware of any precursors to this, so she may have invented this kind of chart. The chart simply called "Lines" is another powerful impetus for change. Appealing to the patriotic reader, the "thin red line" used will have obvious resonance, showing the number of English soldiers dying each year, even when not fighting abroad, compared to civilians of the same age.

Her honeycomb charts represent the amount of space soldiers have – as part of her argument that cramped conditions are inimical to health. She points out that the occupied part of the encampment is "above 50 times more crowded than the population of London". Finally, in something of a tribute to her friend Herbert Spencer, her chart comparing mortality rates in the army before and after his tenure as Secretary of War shows rectangles divided up into areas in proportion to the causes of death – with a clear change for the better while Spencer was running things.

In each case, what's innovative is the mix of getting the appropriate (and correct) data, choosing the perfect visual to represent it, and thereby telling a story to effect change.

## The legacy of Florence Nightingale

Nowadays every company report is bristling with pie charts and histograms; it's easy to forget how revolutionary Nightingale's work was. Her clear-headedness about the importance of good data, and knowing how to interpret it, are examples we would all do well to follow today. And, while she certainly wasn't the first person to use statistical diagrams, she was an early adopter and populariser, she had great instincts for which charts to use to get her message across, and her graphs are a clear argument for change (rather than just a way of reporting data). This is why we rightly remember Florence Nightingale as a pioneer of data visualization. Diagrams like the ones she used are now standard tools. And of course, we can now exploit new technology, like 3-d graphs, and even animations where one can watch the data evolving, for example in the amazing work of people like Hans Rosling. Nightingale believed that statistics was "the most important science in the world": "to understand God's thoughts, we must study statistics for these are the measure of His purpose". For her, the quest to understand statistics was a religious duty.

During the last twenty years of her long life, Florence Nightingale was more or less bed-bound, but she remained an indefatigable letter-writer, and would receive visits from eminent people as she continued campaigning. She died on August 13th 1910, aged 90. Among many honours and achievements, in 1858 she was the first woman to become a Fellow of the Royal Statistical Society, and in 1907 the first woman to be awarded the Order of Merit. Her influence both on nursing and on medical statistics has been profound. The first training school for nurses in the world was the Nightingale Training School for Nurses, which opened at St Thomas' in 1860. Generations of nurses in the US took the Nightingale Pledge during their training, and most recently the temporary medical centres put up in the UK during the pandemic were inevitably christened Nightingale hospitals. Many of us grew up seeing her face on £10 notes, which were in circulation from 1975 to 1992, and were the first British banknotes to feature a female historical figure.

I hope you've enjoyed this look at Florence Nightingale. In our final lecture of this series on unexpected mathematical lives, which started with Christopher Wren – architect but also mathematician – and continued with Florence Nightingale – hero of nursing but also mathematician – I'm going to tell you about Alan Turing – mathematician but also mathematician? We all know about his amazing work on the cryptography and early computing. So, I'm not going to talk about that. I'm going to tell you about his fascinating ideas and work on mathematical biology. I hope to see you for that talk on June 6th.

## Further Reading

- There's a nice article about following the footsteps of the Schiehallion expedition at https://www.bbc.com/travel/article/20211007-how-a-scottish-mountain-weighed-the-planet
- If you want to try reconstructing Nightingale's polar area graph, you can see the table of figures she used, along with many of the diagrams we discussed, in *Mortality of the British Army, At Home, At Home and Abroad, and During the Russian War, As Compared with the Mortality of the Civil Population in England.* 1858 which is available online at https://archive.org/details/mortalityofbriti00lond
- Noel-Ann Bradshaw's article *Florence Nightingale (1820 – 1910): A Pioneer of Data Visualisation* appears in *Women in Mathematics: Celebrating the Centennial of the Mathematical Association of America,* edited by Janet L. Beery, Sarah J. Greenwald, Jacqueline A. Jensen-Vallin, and Maura B. Mast., and published by Springer in 2017. https://doi.org/10.1007/978-3-319-66694-5
- Lynn McDonald is the author of many books and articles on Florence Nightingale, and has also spoken at Gresham College about her – focusing on the Crimean War statistics https://www.gresham.ac.uk/watch-now/florence-nightingale-and-her-crimean-war-statistics-lessons-hospital-safety. She is the director of the Collected Works of Florence Nightingale, a gigantic project to publish all of Nightingales writings. It consists of sixteen published volumes, and a huge amount of archival material has been transcribed and made available online at https://cwfn.uoguelph.ca/ - it's where I got the text of the "letter to Grandmama" about all the animals at the zoo.
- Eileen Magnello is an expert in the history of statistics; two of her papers in the Bulletin (now Journal) of the British Society for the History of Mathematics are especially relevant to my talk today, if you can get hold of them. *Victorian statistical graphics and the iconography of Florence Nightingale's polar area graph (2012)* https://doi.org/10.1080/17498430.2012.618102 includes images of Guerry's polar area diagrams and a letter from Florence to Parthenope. See also *Victorian vital and mathematical statistics (2006)* https://doi.org/10.1080/17498430600964508
- Hugh Small has written several books and articles on Nightingale, including his *Brief History of Florence Nightingale: and Her Real Legacy, a Revolution in Public Health*, 2017. There are links to some of his other books, journal articles and online resources at his website http://www.florence-nightingale-avenging-angel.co.uk/

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