# Funnel Plots

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www.hed.nhs.uk



## Healthcare Evaluation Data (HED)

www.hed.nhs.uk

- Online hospital benchmarking system
- Statistical models and analysis tools
- Activity, Mortality, Readmissions, Length-of-Stay, Marketshare etc.
- Used by ~60 NHS and other organisations
- Training and support

- **Using national NHS HES data**

# HED R Training

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- Two day introduction course, public or onsite. **(24th-25th March, 9th-10th June)**
- We also offer other courses, including:
  - Introduction to R Markdown - **26th Feb**
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# Overview

- What's a funnel plot?
- What's overdispersion?
- What do we do about it?

- *If you are interested (or if we have time):*
  - How to set up and build an R package
  - What I've learned from the process
  - How to publish it to CRAN

https://github.com/chrismainey/FunnelPlotR

# Context:

## Monitoring Standardised Mortality

- How do we compare between organisations with different patients?
- Direct standardisation:
  - Adjust all to common standard (e.g. European Standard Popn)
- Indirectly Standardised Ratios:
  - Predict an expected rate for each unit, based on average (regression model)
  - Case-mix adjustment

$$SR = \frac{\Sigma(\text{observed deaths})}{\Sigma(\text{predicted deaths})}$$

- **Predicted = Expected, but $\neq$ 'preventable'**



# Standardised Ratio example

- 10 identical patients:
  - Risk factor of model
  - E.g. age, sex, primary diagnosis etc.
- If these patients had a probability of death of 0.3 (30%)
  - Expected deaths = 10 * 0.3 = 3
- If we then observed 4 deaths:
  - $> 1$ = higher than expected
  - $< 1$ = lower than expected

# Question:

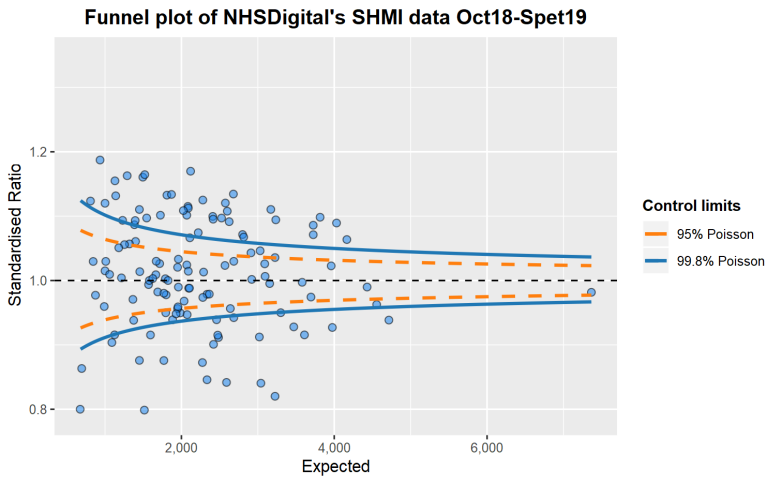
**How can we present these data appropriately?**



# Visualising Uncertainty in SMRs

- Confidence intervals
- Statistical process control charts
- Funnel plots (Speigelhalter, 2005a)

```
## $plot
```



# Funnel Limits and Overdispersion

- Plot above is based on Poisson disribution, used for counts
- Poisson distribution has fixed variance, mean and variance = $\mu$:

$$Pr(Y = y) = \frac{\mu^y e^{-\mu}}{y!}$$

**where:** $\mu$ is the expected average count or rate,

- $e$ is Euler's number (the base of the natural logarithm: ~2.71828),
- and $y!$ is the factorial of y.

## "Real-world" data isn't perfectly Poisson distributed!

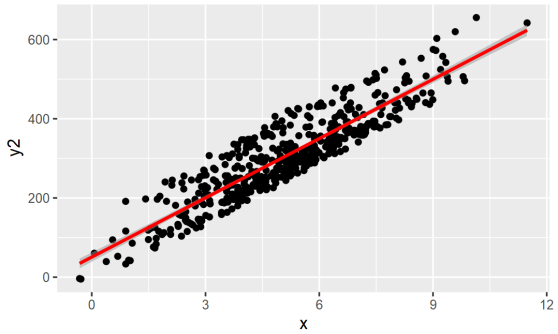
- Causes us to underestimate the error in the data
- Often caused by under-specification, poor parameterisation, clustering, aggregation



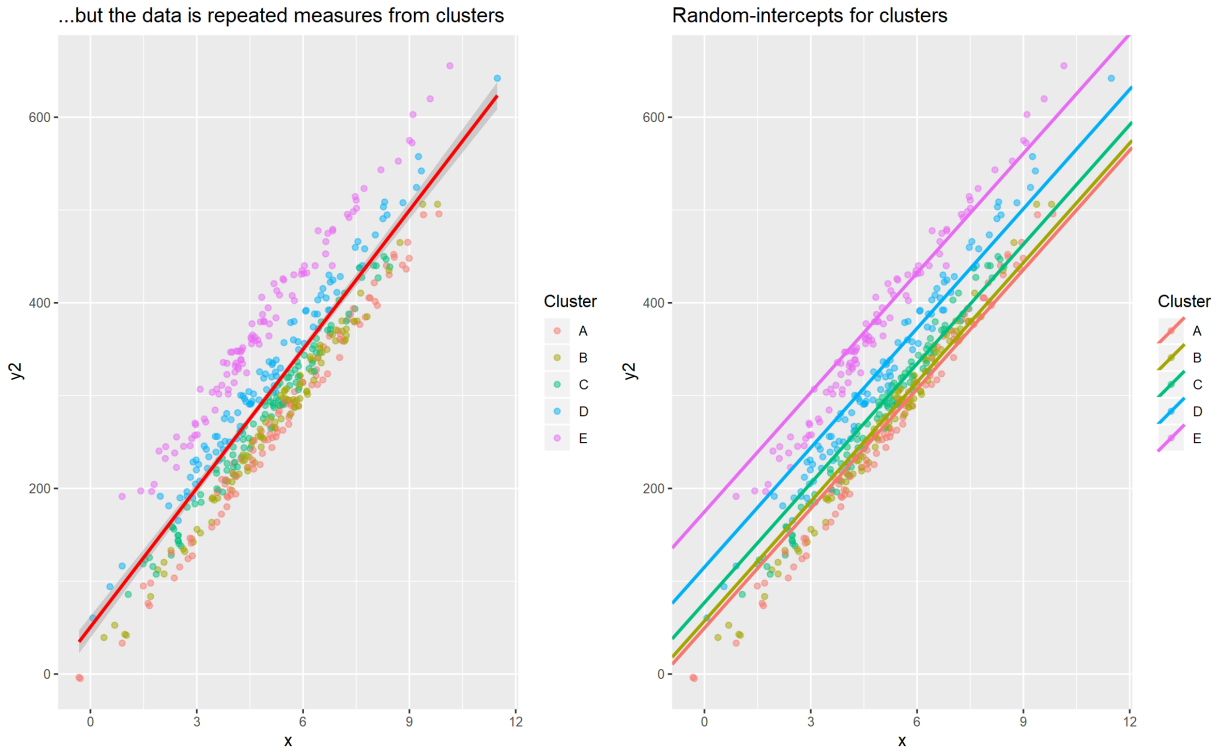
# Clustering of organisations

- Regression assume independence
- We've got repeated measurements form the same organsiation.
- Both *within* trust variation $\sigma$
- And *between* trust variation $\tau$
- Can model with a **random-intercept**

Traditional regression model has single-intercept



# Random-intercepts






# z-scores (1)

- Compare different indicators on standard scale
- Scale indicators by their standard deviation: $\frac{Y - Target}{\sigma^2}$
- This is only valid for normally distributed data
- Proportions, counts & standardised ratios not normally distributed

## Transformations:

- **CQC/Spiegelhalter:** square-root + Winsorization
- **SHMI:** natural logarithm + truncation

## Dispersion ratio is calculated on winsorised/truncated scores:

$$\phi = \frac{\sum_{i=1}^{n} Z_i^2}{n}$$

# z-scores (2)

The dispersion ratio ( $\phi$ ):

- <=1, the set $\tau^2 = 0$
- Otherwise:

$$\tau^2 = \frac{(n\phi - (n-1))}{\sum_{i=1}^{n} W_i - (\sum_{i=1}^{n} W_i^2 / \sum_{i=1}^{n} W_i)}$$

*Where:*

- $W_i$ is $1/\sigma^2$, the within Trust ( $i$ ) standard deviation
- $\phi$ is the dispersion ratio

***These techniques are imprecise estimates of random intercepts in models***



# Funnel Plots

- Control limits commonly 95 and 99% (≈ 2 and 3 σ )
- OD issue:
  - Limits are independent of data, and relate to sample size (predicted)
  - Limits are too tight.
- We can inflate them using the $\tau^2$ calculated above.
- Control limits are then, functionally: $1 \pm z * (\frac{\sigma+\tau}{n})$
- Taken >= 99.8% limits

# Seeing the plot again:

## Poisson limit

```
library(FunnelPlotR)
# lets use NHSD's SHMI dataset: https://digital.nhs.uk/data-and-information/publications/clinical-indi
SHMIdt <- read.csv("Data/SHMI data at trust level, Oct18-Sep19 (csv).csv")
SHMIdt$PROVIDER_NAME <- factor(SHMIdt$PROVIDER_NAME)

funnel_plot(numerator=SHMIdt$OBSERVED, denominator=SHMIdt$EXPECTED, group = SHMIdt$PROVIDER_NAME,
          title = "Funnel plot of NHSDigital's SHMI data Oct18-Spet19",
          Poisson_limits = TRUE,  OD_adjust = FALSE,label_outliers = TRUE, return_elements = "plot")
```

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## $plot
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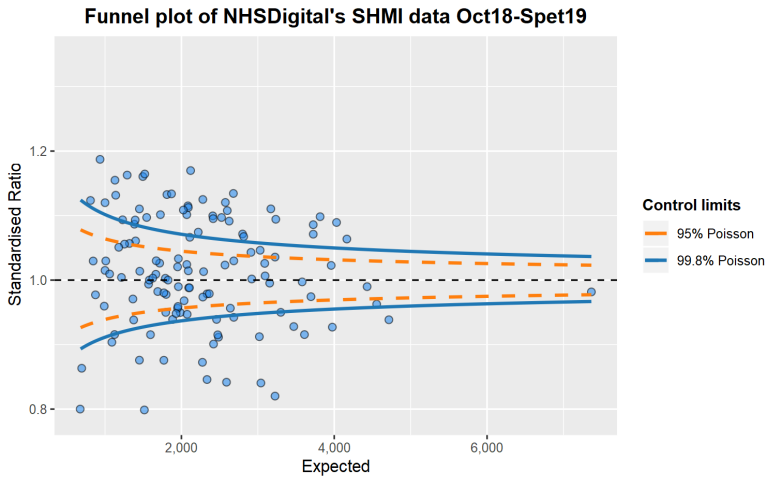




# Seeing the plot again:

## OD adjustment

```
library(FunnelPlotR)
# lets use NHSD's SHMI dataset: https://digital.nhs.uk/data-and-information/publications/clinical-indi
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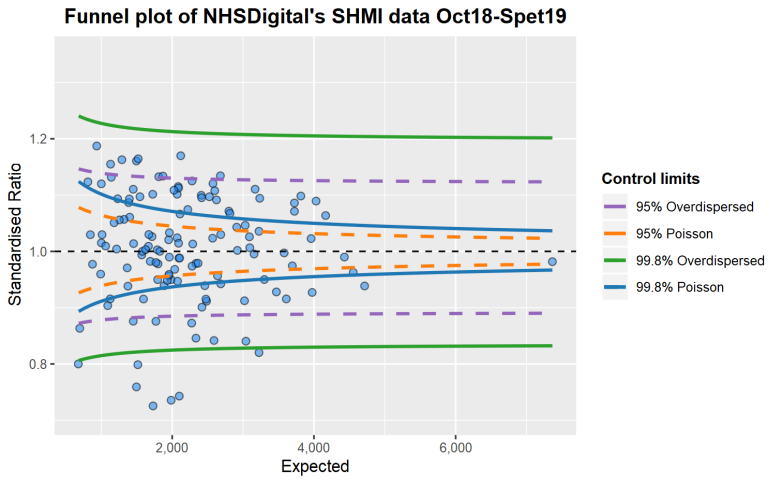


# Issues with Funnel Plots

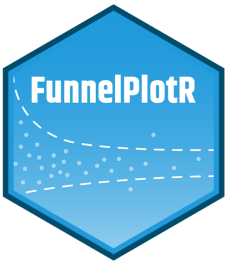
- Are we asking the right question?
- Implicit ranking
- Which limits do we use?
- Overdispersion
  - Assumed to be clustering
  - Adjustment proposed (Spiegelhalter, 2005b)
  - Alternative used by NHSD (with log/truncation)
- Strictly cross-sectional

We could do it better with a mixed model!



# Thank you for your time!

- `FunnelPlotR`
  - Available on CRAN.
  - Contributions and bug reports welcome!

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- HED R Training: https://www.hed.nhs.uk/Info/hed-courses.aspx
  - Intro to R
  - Rmarkdown
  - Regression modelling
  - Machine Learning in R

# References


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- SPIEGELHALTER, D.J., 2005b. Handling over-dispersion of performance indicators. *Qual Saf Health Care,* **14** (5), pp. 347-351 https://www.nhs.uk/NHSEngland/bruce-keogh-review/Documents/outcomes/keogh-review-final-report.pdf