Données en sciences cognitives
Chronométrie mentale
Cours 1

Gabriel Weindel
gabriel.weindel@univ-amu.fr

21 janvier 2020

Plan

1. Introduction
   - The study of reaction times
   - History
2. Method
   - RT as a random variable
   - Mean RT as a random variable
   - Example of real data
3. Modeling
   - Data models
   - Process models
   - Statistical models

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Introduction:

The study of reaction times

What ?

Time from stimulus → Response

Why ?

"If the processing of information by the mind is highly structured [...] then different paths through that structure will entail different time courses, and those differences will be reflected in the response times."

J. Jastrow (1890) as cited by R. D. Luce (1986)

How ?

Experimental design — Measurement technology — Mathematical theorizing

Introduction:

History

The work of Hermann von Helmholtz (1824 - 1894)

"Animal spirit" conduction velocity in frog sciatic nerve = 25 to 43 m/s

Review : *Of frogs and men: the origins of psychophysiological time experiments*, 1850–1865, Schmidgen (2002)

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Signal → transmission → perception and "will" (→ transmission → motor execution)

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What about humans ?

Signal $\rightarrow$ transmission $\rightarrow$ perception and "will" ($\rightarrow$ transmission $\rightarrow$ motor execution)

big toe - ear stimulation $\approx$ 60 m/s

Review : *Of frogs and men: the origins of psychophysiological time experiments*, 1850–1865, Schmidgen (2002)

Introduction:

History

The work of Franciscus Donders (1818 - 1889)

424 F. C. DONDERS

(a) responding to a known sound;
(b) responding to an unknown sound;
(c) responding to one of the unknown sounds.

With each of these ways the average duration and the minimum were recorded:

thousandths of a second

for (a) the average duration 201, the minimum 170.5
(b) the average duration 284, the minimum 237.5
(c) the average duration 237, the minimum 212.6

the following values are now found:

	from the averages	from the minima	averaged
b-a =	83	67	75
c-a =	36	42	39

On the speed of mental processes, F. C. Donders (1969, réédition)

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- Simple RT task
- Choice RT task
- go/no-go RT task

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Method:

History

How would you reproduce the experiment from Donders?

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Multiple trials, why ?
$\rightarrow$ RTs is a random variable

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History

How would you reproduce the experiment from Donders?

Multiple trials, why ?
$\rightarrow$ RTs is a random variable

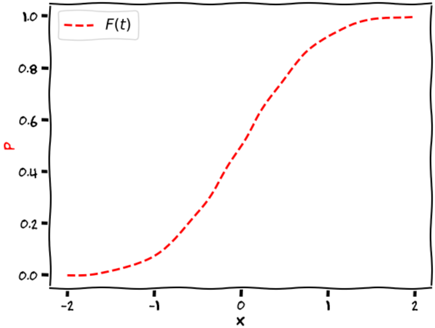
Multiple subjects, why ?
$\rightarrow$ Because we want to generalize the results to the population

Method:

RT as a random variable

$\boldsymbol{T}$ is the RV denoting a person's response time in given conditions
t any real number

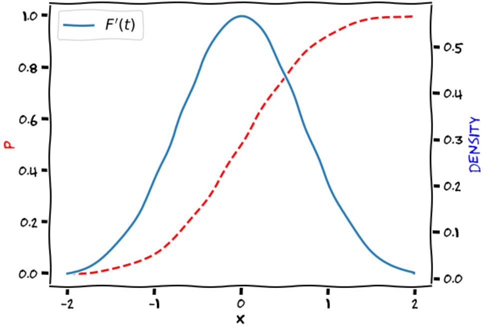
$F(t) = p(\boldsymbol{T} \leq t)$



Method:

RT as a random variable

$$F'(t) = dF(t)/dt$$

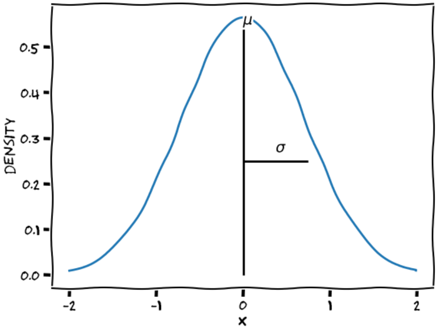


Method:

RT as a random variable

In this example the distribution is a normal defined by a mean (μ) and a scale (σ)

$$x \sim \mathcal{N}(\mu, \sigma)$$



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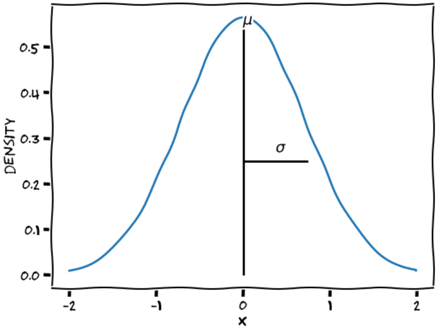


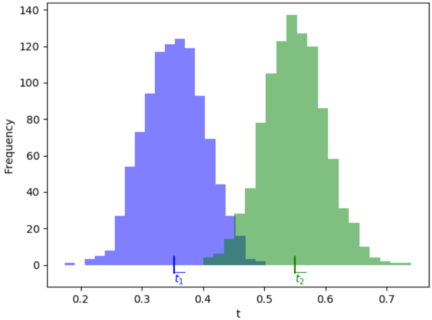
Donders wanted to know the difference between μ_{SRT} and μ_{GNg} to infer the mean duration of the stimulus selection stage (for a single subject)

Method:

RT as a random variable

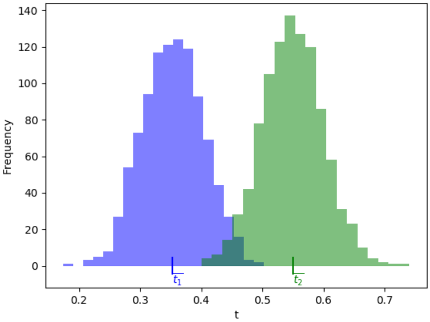
But μ is unknown, hence we have to approximate μ based on the observed samples $t_1, \ldots, t_n$, :

Empirical mean $= \bar{t} = \frac{t_1 + \cdots + t_n}{n}$
$\mathbb{E}(\bar{t}) = \mu$



Method:

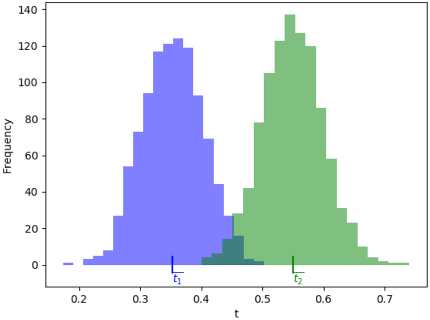
RT as a random variable



Hence to test Donders hypothesis we compare $\bar{t}_{SRT}$ and $\bar{t}_{GNg}$ (e.g. t-test, testing $\mathcal{H}_{\mathcal{O}} : \mu_{SRT} = \mu_{GNg}$)

Method:

RT as a random variable



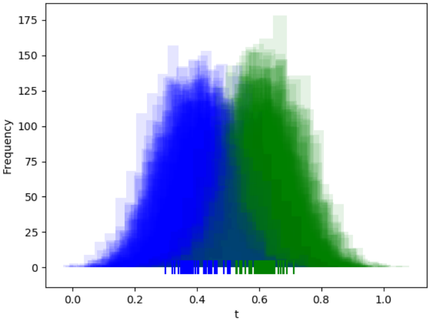
Hence to test Donders hypothesis we compare $\overline{t}_{SRT}$ and $\overline{t}_{GNg}$ (e.g. t-test, testing $\mathcal{H}_{\mathcal{O}} : \mu_{SRT} = \mu_{GNg}$)

But we want to generalize to the population !

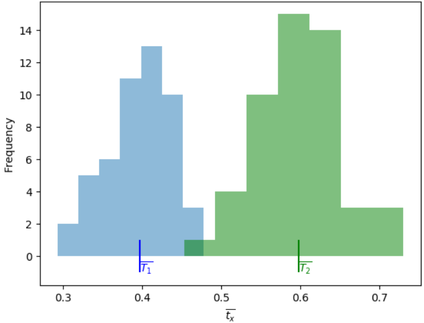
Method:

Mean RT as a random variable

We sample x participants from the population in two conditions



We can look at the distribution of $\overline{t_{x1}}$ and $\overline{t_{x2}} \rightarrow$
and compute grand average for each condition ($\overline{T_1}$ and $\overline{T_2}$)



Method:

Mean RT as a random variable

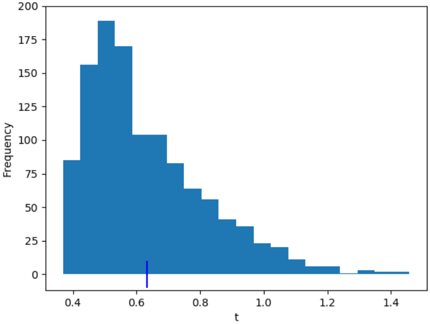
In these conditions I can test for a difference using my favorite statistical model (see last section, e.g. t-test) as most researchers would do.

However RT data are special data.

Method:

Example of real data

Real RT data are (almost) never normal, example for one individual :



- unimodal with heavy right skew
- High variation within and between participants
- Independent Variables (IVs) tend to change the mean and the scale

Method:

Example of real data

Additionally with choice RTs participants always perform a SAT

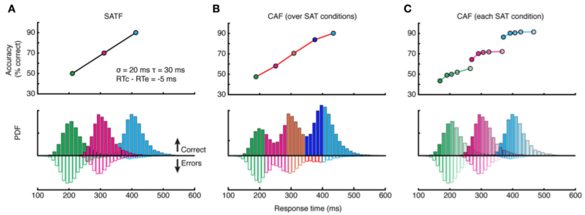


FIGURE 3 | Comparison of the SATF, overall CAF, and individual CAFs in the same simulated dataset. (A) The SATF is simply the mean RT and accuracy rate for each SAT condition Here, they were 225, 325, and 425 ms response deadlines. The manipulation was effective by definition, yielding accuracy rates of 50, 70, and 90%, respectively. Each condition was constructed by drawing $N = 10,000$ observations randomly from an ex-Gaussian distribution with parameters indicated in figure inset. Solid histograms depict correct trials, open histograms error trials. **(B)** The same data as **(A)** but aggregated disregarding SAT condition and plotted as a CAF. **(C)** Same data as **(A,B)** but CAFs computed separately for each deadline condition.

(Heitz, 2014)

Method:

Example of real data

Hence mindlessly using simple statistical models (e.g. use the grand average of participants mean in a t-test) to answer questions about mental chronometry is highly limited (if not useless).

Hence we need proper statistical tools to model RT data.

Plan

Modeling

We can distinguish three kind of models :

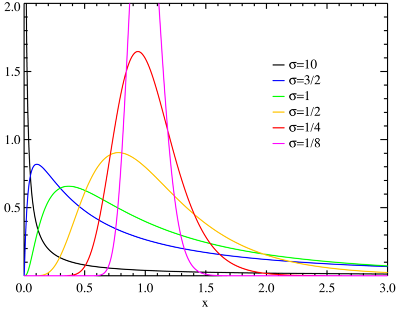
- Data models $\rightarrow$ Describing the data
- Process models $\rightarrow$ Approximate the "assumed" generative model of the data
- Statistical models $\rightarrow$ Describe the variation of the data with independent variables

The latter kind of models can, and should, be combined with the preceding ones.

Modeling:

Data models

Log-normal distribution :
Data follows a log-normal distribution if $Y = ln(t)$ follows a normal distribution.



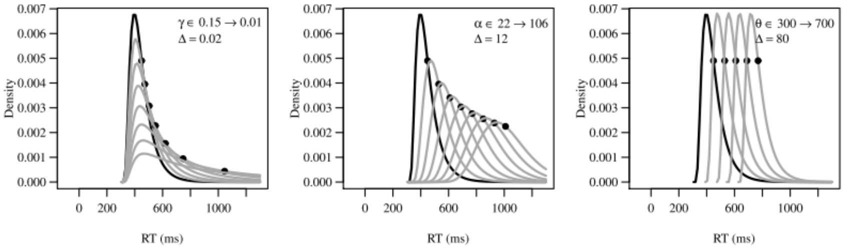
wikipedia.org

But the validity of the log-transform is contested...

Modeling:

Data models

The shifted wald (Anders, Alario & van Maanen, 2014) :



Three parameters (γ, α, θ) describe respectively, the mass of the tail, the deviation around mode and the onset of the distribution.

Modeling:

Data models

The ex-gaussian (Hohle, 1965), exponential and normal stages :

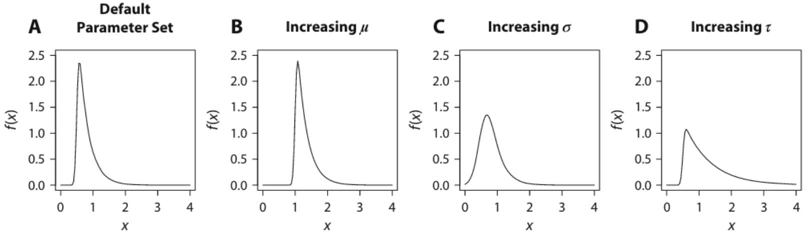


Figure 1. Changes in the ex-Gaussian distribution as a result of changes in the ex-Gaussian parameters μ, σ, and τ. The parameter sets used to generate the distributions are (A) $\mu = 0.5, \sigma = 0.05, \tau = 0.3$ (default parameter set); (B) $\mu = 1, \sigma = 0.05, \tau = 0.3$ (increasing μ); (C) $\mu = 0.5, \sigma = 0.2, \tau = 0.3$ (increasing σ); and (D) $\mu = 0.5, \sigma = 0.05, \tau = 0.8$ (increasing τ).

μ and σ represent the mean and the scale of the normal component and τ the scale of the exponential.

Modeling:

Data models

But while data models do model the data better than a normal, they do not provide natural sense of the descriptive statistic of interest

Modeling:

Process models

Random walk/diffusion models (Stone, 1960; Ratcliff, 1978), applicable to RT data from choice RT tasks

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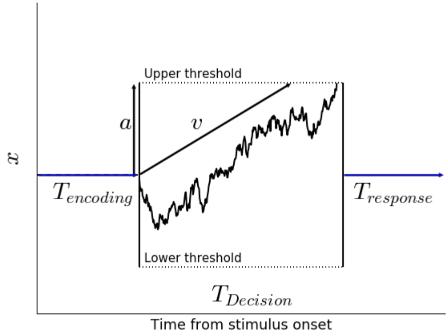

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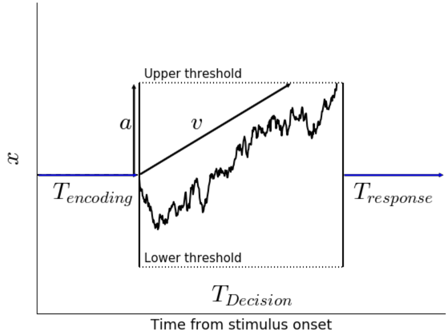
Process models

Random walk/diffusion models (Stone, 1960; Ratcliff, 1978), applicable to RT data from choice RT tasks



Wagenmakers, van der Maas et Grasman (2007) :

$$TRM = TDM + T_{er} \quad (1)$$

$$TDM = \left(\frac{a}{2v}\right) \frac{1 - e^{-va/s^2}}{1 + e^{-va/s^2}} \quad (2)$$

$$P_u = \frac{1}{1 + e^{-av/s^2}} \quad (3)$$

Modeling:

Process models

In a process model, parameters are used to infer on the (assumed) cognitive processes, e.g. in the diffusion model

- accumulation speed (v) $\rightarrow$ processing speed of the stimulus
- decision boundary (a) $\rightarrow$ response precaution
- Non-decision time (T_{er}) $\rightarrow$ residual time (e.g. stimulus encoding and response execution)

We can therefore test IVs on the parameters of interest (e.g. does age reduce processing speed of the stimulus)

Modeling:

Statistical models

Statistical models are built on top of the model used to describe the data.

e.g. using an independent t-test (equal sample size and variance) to model the effect of a categorial IV (e.g. Age, old vs. young) on the grand average mean RT ($\overline{T}$) :

$$t_{value} = \frac{\overline{T}_{old} - \overline{T}_{young}}{s_p \sqrt{\frac{2}{n}}}$$

where

$$s_p = \sqrt{\frac{s^2_{T_{old}} + s^2_{T_{young}}}{2}}$$

The same could be done on the accumulation speed (v) of a Diffusion model.

Modeling:

Statistical models

Linear Models are extremely useful statistical tool, they describe linear relationship between the IV (e.g. Age, continous) and a measure (e.g. $\overline{T}$) :

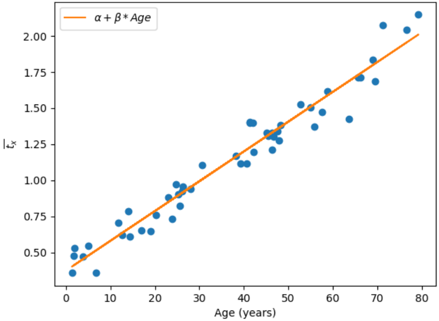
$$\overline{t_x} \sim \mathcal{N}(\mu, \sigma)$$

$$\mu = \alpha + \beta * IV$$

Modeling:

Statistical models

Linear Models are extremely useful statistical tool, they describe the linear relationship between the IV (e.g. Age, continous) and a measure (e.g. $\overline{T}$) :



Modeling:

Statistical models

However, linear models :

- use only little information about the data ($\overline{t_x}$)
- do not allow to model random effects (e.g. inter-individual difference)
- cannot weight participants according to their contribution (e.g. high vs. low trial rejection rate for a participant = same weight in a linear model)

Hence we need a tool that can both account for the hierarchy of the RT data (t nested within participants) and model random effects (e.g. the inter-individual difference of big toe vs ear stimulation).

$\Longrightarrow$ Linear Mixed Models