MRC Cognition and Brain Sciences Unit

UNIVERSITY OF CAMBRIDGE

Human Cognitive Neuroscience And How It Is Taught

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COGNESTIC 2022

Why Care About Methods (Training)?

- Provide researchers with **state-of-the-art research tools** that are not part of standard cognitive psychology or neuroscience courses, stimulation creative work and possibly enabling new lines of research.
- Enable researchers to **analyse data more efficiently and accurately**, minimising errors and freeing more time for other activities.
- Facilitate **communication** among scientists from different fields in an **interdisciplinary** research environment.
- Provide students and post-docs with **transferable skills** that will be useful for future job hunting.
- Health & Safety

Why Care About Methods (Training)?

If you are planning some DIY, you are asking yourself:
Do I have the skills and experience?
Do I have the material?
Do I have the tools?

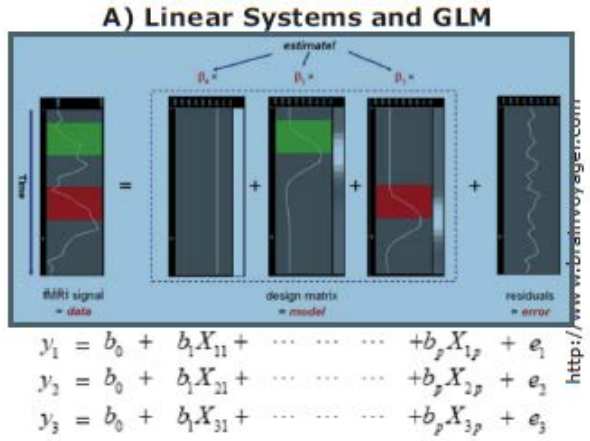
When you are travelling to a new country, you are asking yourself:
Do I know the language?
Do I know the infrastructure?
Am I prepared for the climate?

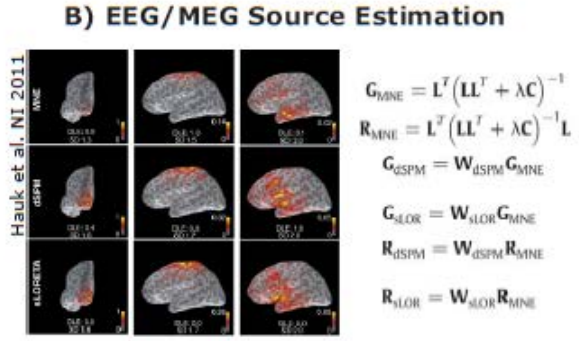
Why Care About Methods (Training)?

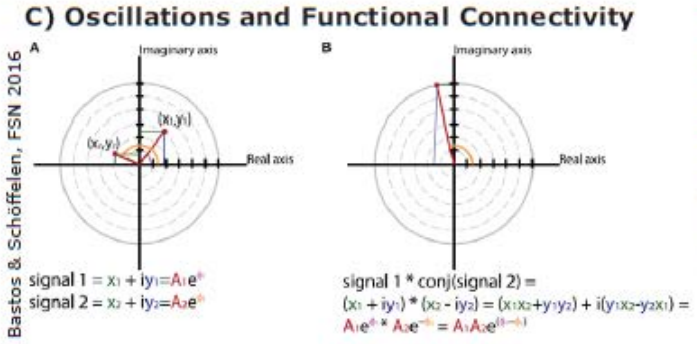
You don’t need to know how an engine works to drive a car –
unless you drive a faulty car on your own far away from any garage in very bumpy terrain.

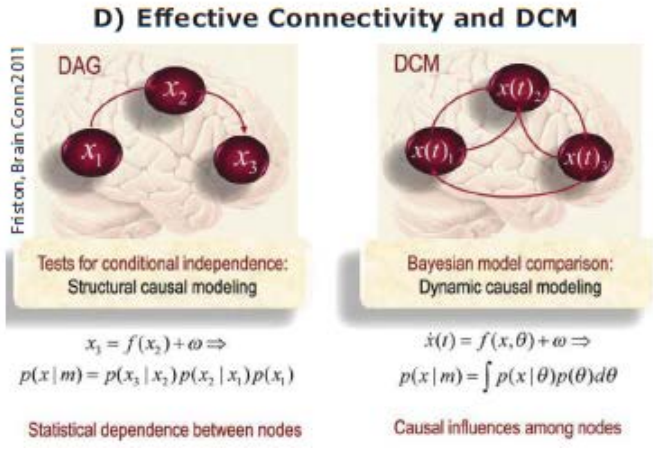
Challenges Of Interdisciplinary Research

“Linking hypothesis”:
We are interested in cognitive/brain functions –
based on evidence from physical measurements.









from Hauk, Front Psychol 2020

Quotes

"Danilevsky (1852-1939) … finished his thesis entitled 'Investigations into the Physiology of the Brain' (1877). … He published an extensive textbook of human physiology in 1915. … He saw his high hopes unfulfilled as far as the spontaneous electrical activity of the brain was concerned. … He was not the only EEG researcher with shattered hopes in the field of psychophysiology".
From: Niedermeyer and Schomer, 2011

"The mistakes in electroencephalography can fairly be attributed to ignorance of the theory underlying either the behaviour of the material or the equipment used to study it."
W.G. Walter & G. Parr (1950).

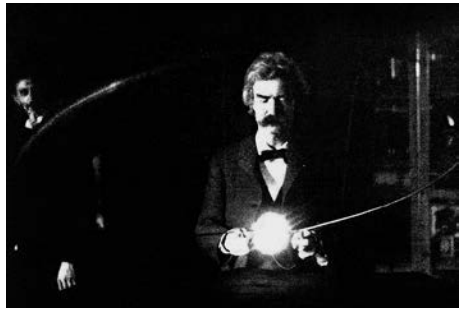
"Inappropriate computer methods are worse than no computer methods at all."
Nunez&Srinivasan, 2006, Electric Fields of the Brain, p. 91

"No matter how enmeshed a commander becomes in the elaboration of his own thoughts, it is sometimes necessary to take the enemy into account."
Winston Churchill

"It is not enough to set tasks; we must also solve the problem of the methods for carrying them out. … Unless the problem of method is solved, talk about the task is useless."
Mao Zedong, Quotations

Challenges Of Interdisciplinary Research

From: Mark Twain's "English How She Is Taught"



CAPILLARY:
a little caterpillar.

EQUESTRIAN:
one who asks questions.

FRANCHISE:
anything belonging to the French.

Here is one which--well, now, how often we do slam right into the truth without ever suspecting it:

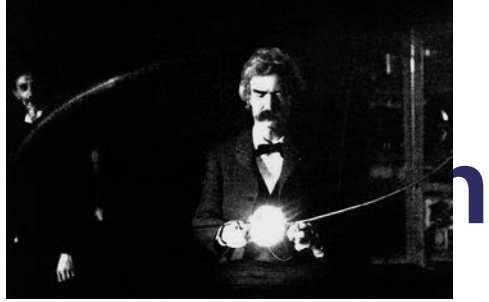
The men employed by the Gas Company go around and speculate the meter.

In the following sentences the little people have some information to convey, every time; but in my case they fail to connect:

The supercilious girl acted with vicissitude when the perennial time came.

The last is a curiously plausible sentence; one seems to know what it means, and yet he knows all the time that he doesn't.

Challenges Of Interdisciplinary



From: Mark Twain's "English How She Is Taught"

Mathematics

- A straight line is any distance between two places.
- Parallel lines are lines that can never meet until they run together.
- A circle is a round straight line with a hole in the middle.
- Things which are equal to each other are equal to anything else.
- To find the number of square feet in a room you multiply the room by the number of the feet. The product is the result.

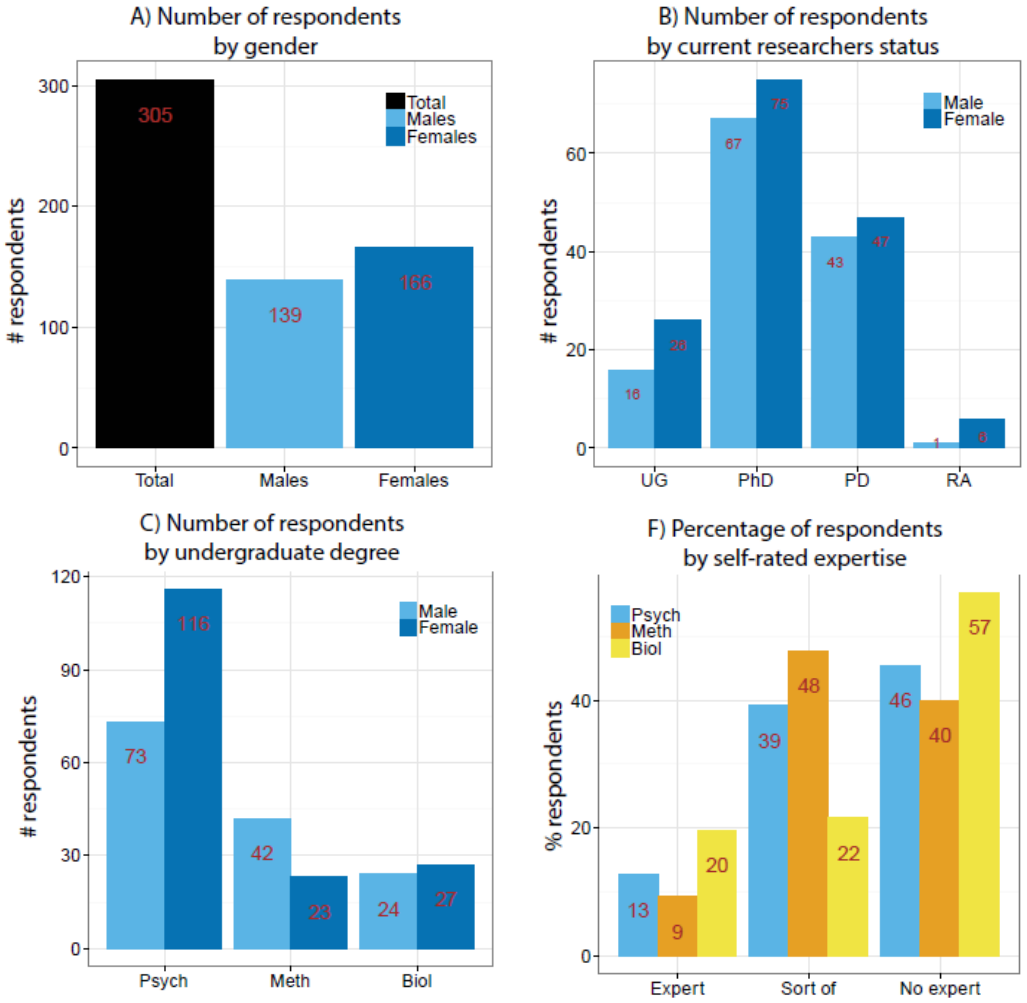
Geography

- Ireland is called the Emigrant Isle because it is so beautiful and green.

Physics

- The spheres are to each other as the squares of their homologous sides.
- A body will go just as far in the first second as the body will go plus the force of gravity and that's equal to twice what the body will go.
- Specific gravity is the weight to be compared weight of an equal volume of or that is the weight of a body compared with the weight of an equal volume.

Methods Skills Survey - Demographics



Hauk, Front Psychol 2020
https://www.frontiersin.org/articles/10.3389/fpsyg.2020.587922/full

Methods Skills Survey – Example Questions

Linear Algebra

What is the (scalar) product of the two vectors [1 2] and [3 4]?

- 4
- 21
- 10
- 11

Which of these pairs of vectors are orthogonal?

- [1 2], [1 2]
- [0 1], [0 1]
- [1 2], [3 4]
- [1 -2], [2 1]

Methods Skills Survey – Example Questions

Programming

An integer number is

- a number that can be written without a fractional component
- a number that cannot be divided
- a prime number smaller than 100
- a positive number

In software programming, a “for loop” is a statement that

- circumvents an error message
- asks for further information
- allows a piece of code to be repeatedly executed
- lets the program return to a previous statement

Methods Skills Survey – Example Questions

Signal Analysis

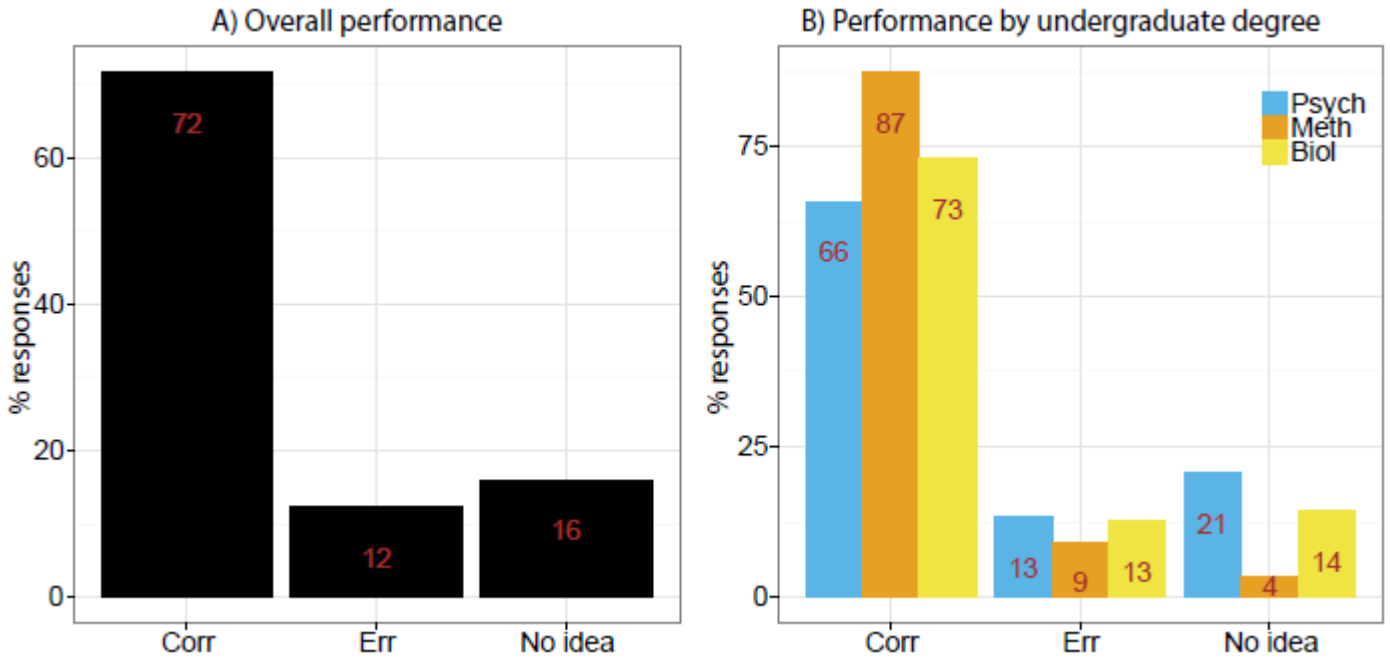
The “signal to noise ratio” (SNR) refers to

- a measure for the amplitude of the desired part of the signal divided by a similar measure for the undesired part of the signal
- a measure for the amplitude of the undesired part of the signal divided by a similar measure for the desired part of the signal
- the ratio between two random signals
- a statistical comparison between a structured and a random model

If you have two signals with frequencies f1 and f2, then the sum of these signals has peaks in the frequency spectrum at which frequency or frequencies?

- f1+f2 and f1-f2
- f1 and f2
- f1*f2
- (f1+f2)/2

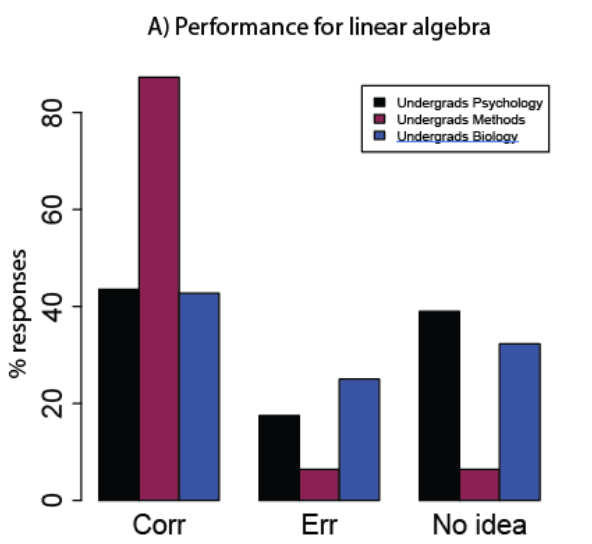
Methods Skills Survey – Performance Among Junior Researchers

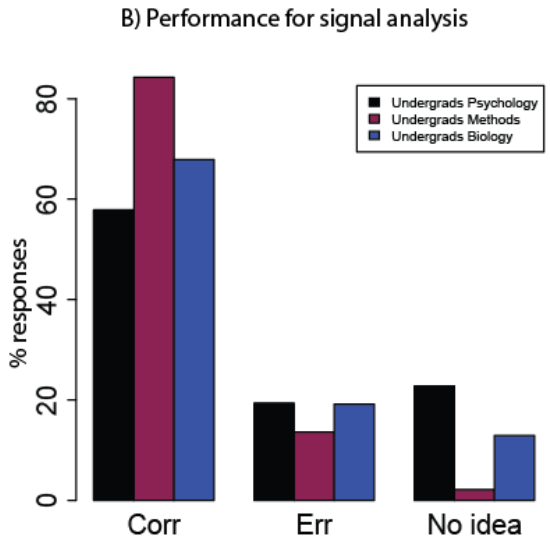


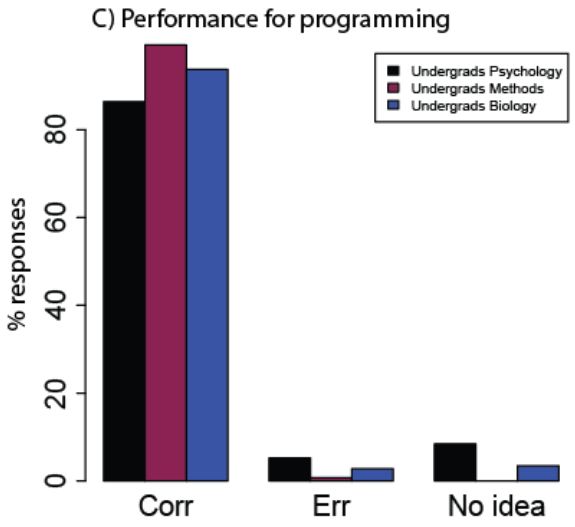
Not surprising.

Hauk, Front Psychol 2020
https://www.frontiersin.org/articles/10.3389/fpsyg.2020.587922/full

Methods Skills Survey – Performance Among Junior Researchers







Performance is worst in areas that matter the most, especially for participants from non-methods backgrounds.

Hauk, Front Psychol 2020
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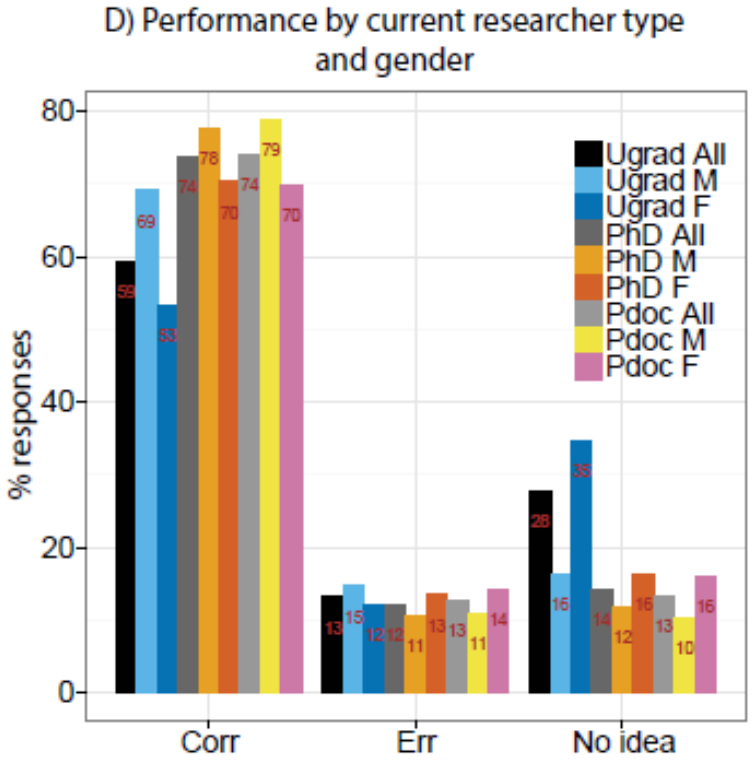

Methods skills plateau at PhD stage.

Hauk, Front Psychol 2020
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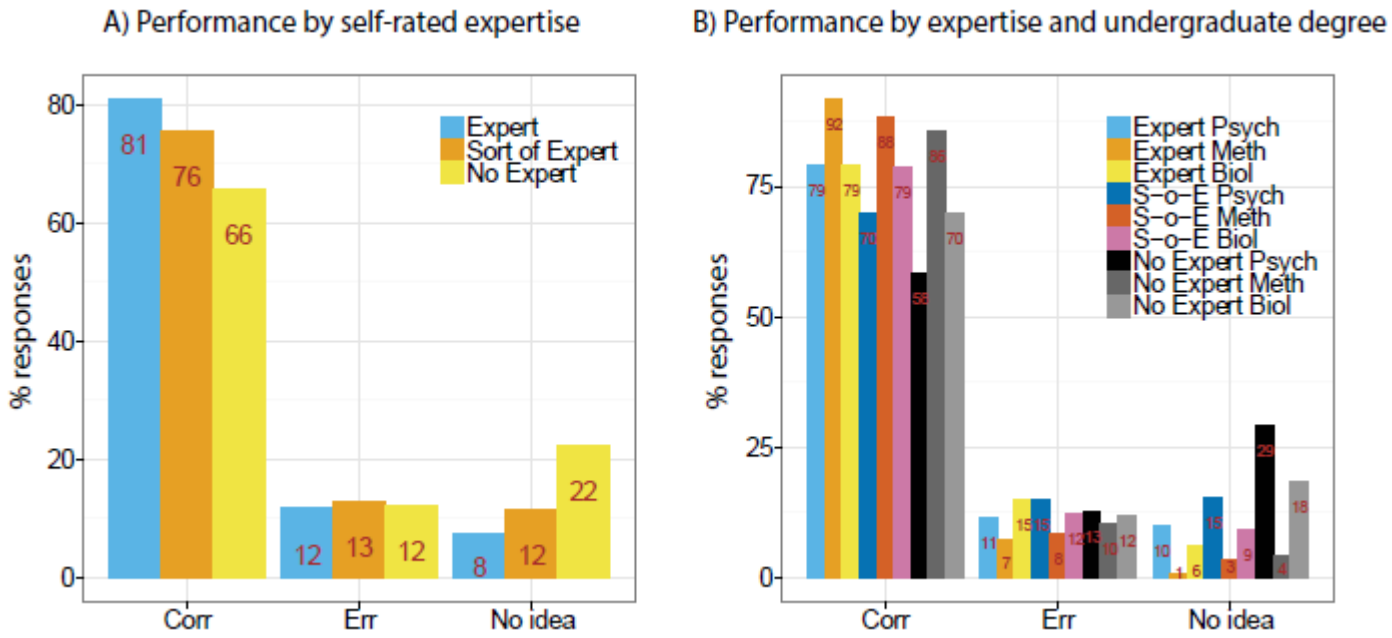
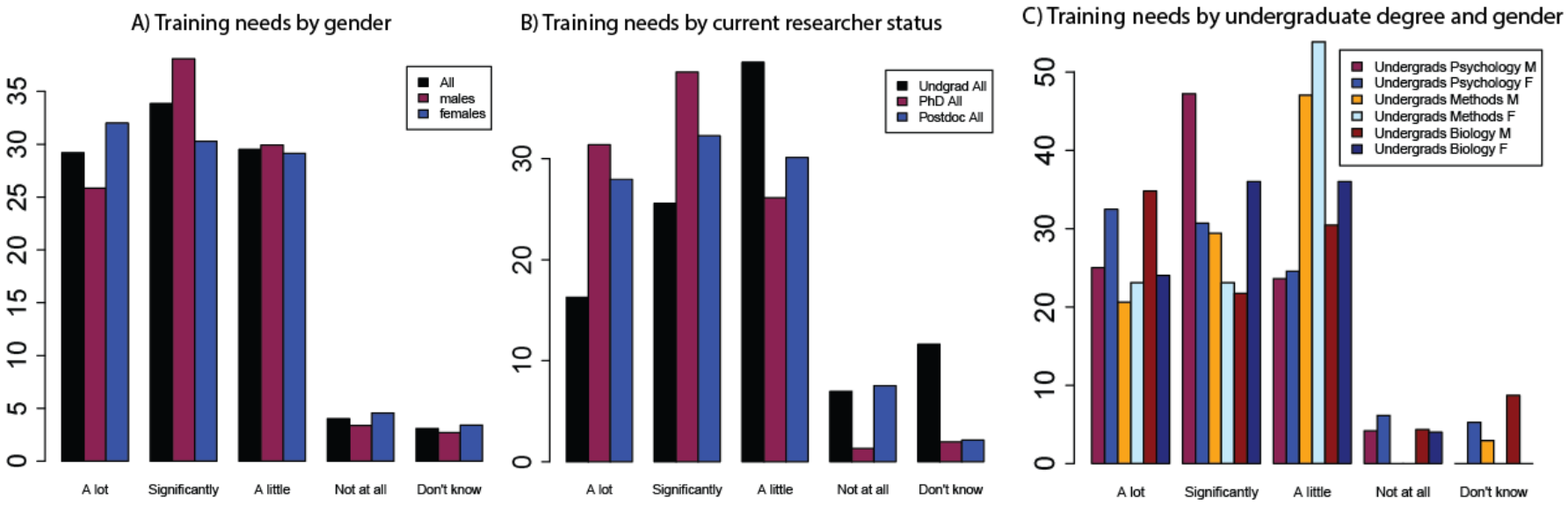


Self-rated expertise matters surprisingly little. What is an “expert”?
Maybe to some “expert” means “doing a lot”, rather than “understanding a lot”.

Hauk, Front Psychol 2020
https://www.frontiersin.org/articles/10.3389/fpsyg.2020.587922/full

Methods Skills Survey - Demand For More Skills-Oriented Training



Most respondents want more methods-oriented training.
More so among PhD students and post-docs than undergrads.

Hauk, Front Psychol 2020
https://www.frontiersin.org/articles/10.3389/fpsyg.2020.587922/full

Conclusions from Methods Skills Survey

- Performance is worst in areas that matter the most, especially for participants from non-methods backgrounds.

- Methods skills plateau at PhD stage.

- Self-rated expertise matters surprisingly little.
- Maybe to some “expert” means “doing a lot”, rather than “understanding a lot”.

- Most respondents want more methods-oriented training.
- More so among PhD students and post-docs than undergrads.

- What about you?

What Is A Good Theory?

It should be based on explanatory principles.

It should predict measurements (replicably).

It should be generalisable (possibly applicable outside the laboratory).

It should be quantitative (?).

A Good Theory: Newton’s Laws Of Motion

http://creativecan.com/2012/04/macbook-stickers/

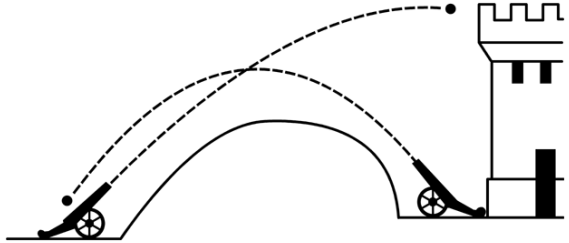
Inertia:
An object changes its velocity only in reaction to an external force.

F = m*a:
The net force acting on an object is proportional to its mass and its acceleration.

Actio et Reactio:
If one body exerts a force on a second body, the second body exerts a force of the same magnitude on the first body.

Not Only A Good Theory

The theory doesn't just apply to some objects in some laboratory experiments, but to lots of stuff such as dropping stones, moving vehicles, canon balls, planets…

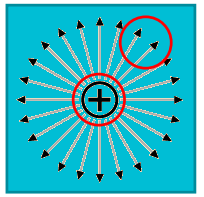


It's a "good theory", even though it's "wrong" (quantum & relativity theory are better) – but it has a clear range of validity.

Another Good Theory: Maxwell's Equations

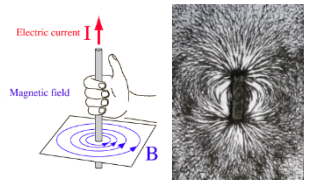
Generation of electric and magnetic fields by electric charges and currents

The summed electric flux around a closed surface is proportional to the total electric charge enclosed within this surface (Gauss's Law).



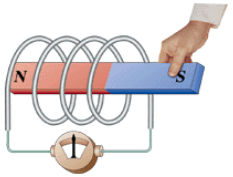
$$\nabla \cdot \boldsymbol{E} = \frac{\rho}{\varepsilon_0}$$

Magnetic field lines are closed (Gauss's Law for magnetism, *no "magnetic monopoles").*



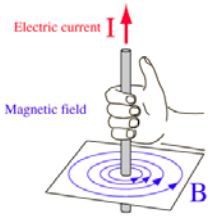
$$\nabla \cdot \boldsymbol{B} = 0$$

Changing magnetic fields produce an electric field (Faraday's Law of Induction).



$$\nabla \times \boldsymbol{E} = -\frac{d\mathbf{B}}{dt}$$

Currents and changing electric fields produce magnetic fields (Ampere's Law).

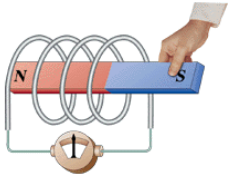


$$\nabla \times \boldsymbol{B} = \mu_0 \left(\mathbf{J} + \varepsilon_0 \frac{d\mathbf{E}}{dt} \right)$$

Another Good Theory: Maxwell's Equations

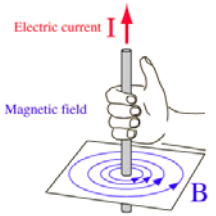
Changing magnetic fields produce an electric field proportional to the rate of change (Faraday's Law of Induction).

$$\nabla \times \boldsymbol{E} = -\frac{d\mathbf{B}}{dt}$$



Magnetic fields can be caused by currents and changing electric fields (Ampere's Law).

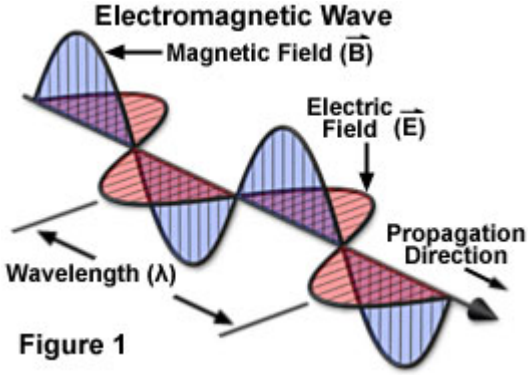
$$\nabla \times \boldsymbol{B} = \mu_0 \left(\mathbf{J} + \varepsilon_0 \frac{d\mathbf{E}}{dt} \right)$$



Wave equations:

$$\frac{1}{c^2}\frac{d^2\mathbf{E}}{dt^2} - \nabla^2 \boldsymbol{E} = 0$$

$$\frac{1}{c^2}\frac{d^2\mathbf{B}}{dt^2} - \nabla^2 \boldsymbol{B} = 0$$



Not Just A Good Theory

How Is This Relevant For Cognitive Science?

“There Is Nothing So Theoretical as a Good Method”

Anthony G. Greenwald, Perspective on Psychological Science 2012

“There is nothing so practical as a good theory” (Lewin, 1951):

Established theories include rules of correspondence that connect the theory’s concepts and principles to empirical observations.

When a theory is “good” (in Lewin’s sense), its rules of correspondence go beyond assigning conceptual labels to laboratory research procedures.

They extend the theory’s concepts and principles to the nonlaboratory world—in other words, to the possibility of useful applications.

Psychology’s most elite empirical journals often oblige authors to establish the value of submitted articles by making clear how their empirical work “advances theory.”

Theories In Psychology

Table 1. Some of Psychology's Theory Competitions

Phenomenon	Competing theories	Initial or early publication	Controversy-resolving publication
Sapir–Whorf hypothesis	Language/culture does (or does	Whorf (1956)	
Structure		owlis and Nowlis (1956)	
Counterattitudinal role playing	Dissonance vs impression		
Memory search	Serial vs. paral		
Implicit learning	Rules vs. asso		
Mental rotation	Analog vs. propositional representation	Shepard and Metzler (1971)	
Semantic priming	Spreading activation vs. compound cueing	Meyer and Schvaneveldt (1971)	
Categorization	Features, exemplars, prototypes, rules	Labov (1973)	
Altruism	Intrinsic vs. extrinsic motivation	Cialdini, Darby, and Vincent (1973)	
Misleading information	Altered traces vs. independent	Loftus and Palmer (1974)	
Judgme		rsky and Kahneman (1974)	
Affect–	primacy	onc (1980)	
Memory dissociations	Modules vs. processes vs. thresholds	Jacoby and Dallas (1981)	

Mathematical modelling: a bit of both
Townsend&Fific 2004

Brain Imaging & Neuropsychology: a bit of all
Smith & Grossmann 2008

Brain Imaging: Analog (visual imagery)
Kosslyn, Ganis et al. 2004

Greenwald, PPS 2012

Most if not all of those controversies are still active.

"publications that were treated by one side as crucial opposition falsifying findings were generally greeted by the opposed side as conceptually or empirically flawed efforts."

The Best Way To The Nobel Prize

1991 to 2011:

	Medicine	Chemistry	Physics	Total
Theory	2	4	8	14
Method	21	22	20	63

82% for method, 18% for theory

Psychology-related Nobel Prizes:

Year	Prize	Awardee(s)	Citation
1949	Medicine	Walter Rudolf Hess	For his discovery of the functional organization of the interbrain as a coordinator of the activities of the internal organs
1961	Medicine	Georg von Békésy	For his discoveries of the physical mechanism of stimulation within the cochlea
1967	Medicine	Ragnar Granit, Haldan K. Hartline, George Wald	For their discoveries concerning the primary physiological and chemical visual processes in the eye
1973	Medicine	Karl von Frisch, Konrad Lorenz, Nikolaas Tinbergen	For their discoveries concerning organization and elicitation of individual and social behavior patterns
1978	Economics	Herbert A. Simon	For his pioneering research into the decision-making process within economic organizations
1981	Medicine	Roger W. Sperry	For his discoveries concerning the functional specialization of the cerebral hemispheres
1981	Medicine	David H. Hubel, Torsten N. Wiesel	For their discoveries concerning information processing in the visual system
2000	Medicine	Avid Carlsson, Paul Greengard, Eric Kandel	For their discoveries concerning signal transduction in the nervous system
2002	Economics	Daniel Kahneman	For having integrated insights from psychological research into economic science, especially concerning human judgment and decision-making under uncertainty

7 out of 9 for methods, 2 half-half (O'Keefe probably methods)

Greenwald, PPS 2012

Can A Biologist Fix A Radio?

Or, what I learned while studying apoptosis

Lazebnik, Cancer Cell 2002

Figure 1. The radio that has been used in this study

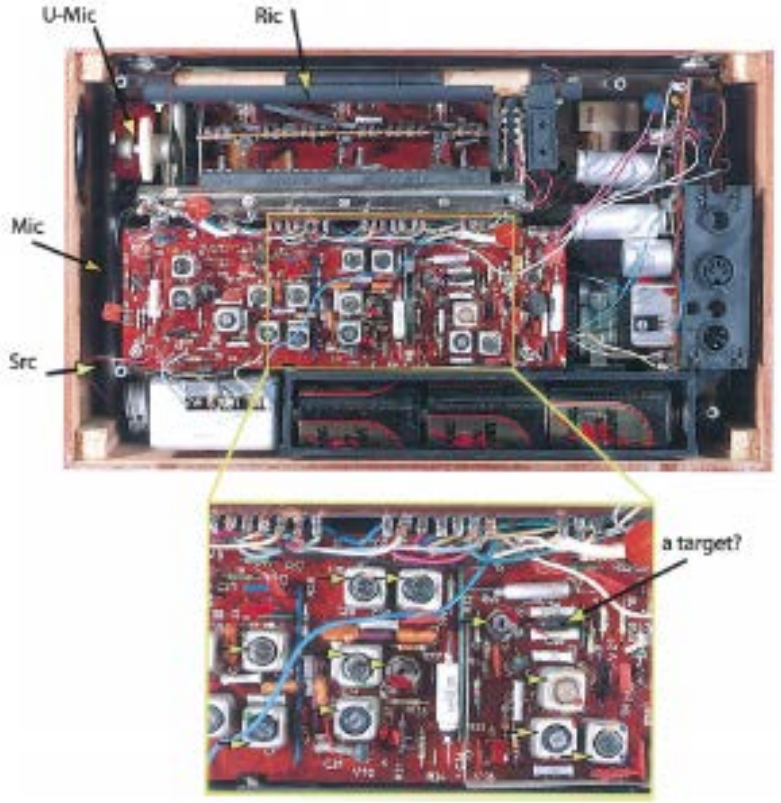


Figure 2. The insides of the radio

Can A Biologist Fix A Radio?

Or, what I learned while studying apoptosis

Lazebnik, Cancer Cell 2002

How would we begin? ... We would eventually find how to open the radios and will find objects of various shape, color, and size. We would **describe and classify** them into families according to their appearance. ... Because the objects would vary in color, we would investigate whether changing the colors affects the radio's performance. …

A more successful approach will be to remove components one at a time or to use a variation of the method, in which a radio is shot at a close range with metal particles. … Although **removing some components** will have only an attenuating effect, a lucky postdoc will accidentally find a wire whose deficiency will stop the music completely.

The jubilant fellow will **name** the wire Serendipitously Recovered Component (Src) and then find that Src is required because it is the only link between a long extendable object and the rest of the radio. The object will be appropriately named the Most Important Component (Mic) of the radio. A series of studies will definitively establish that Mic should be made of metal and the longer the object is the better, which would provide an evolutionary explanation for the finding that the object is extendable.

Can A Biologist Fix A Radio?

Or, what I learned while studying apoptosis

Lazebnik, Cancer Cell 2002

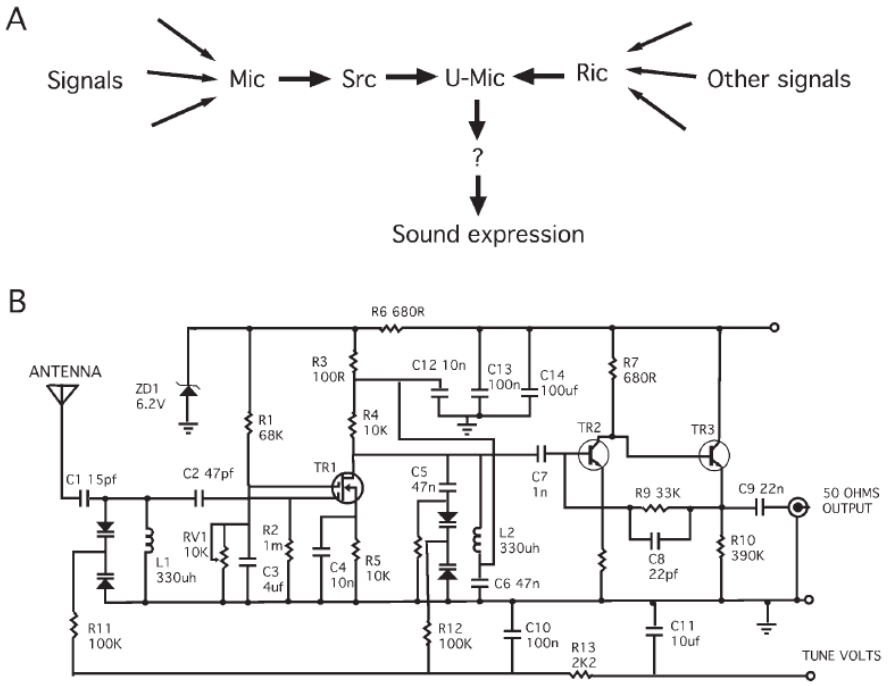


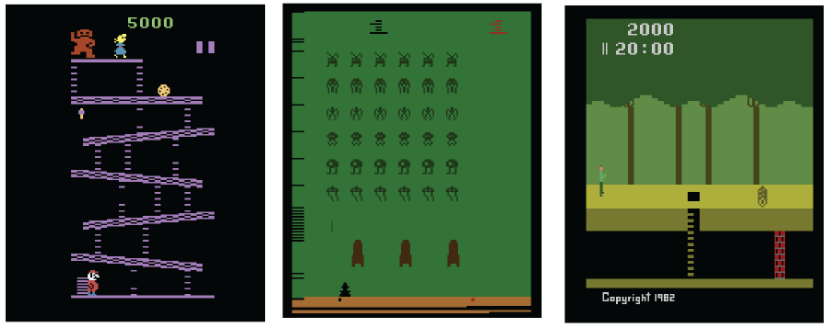
Figure 3. The tools used by biologists and engineers to describe processes of interest

A: The biologist's view of a radio. See Figure 2 and text for description of the indicated components. **B:** The engineer's view of a radio. (Please note that the circuit diagram presented is not that of the radio used in the study. The diagram of the radio was lost, which, in part, explains why the radio remains broken.)

These description and communication tools are in a glaring contrast with the language that has been used by engineers (compare Figures 3A and 3B). Because the language (Figure 3B) is standard …, any engineer trained in electronics would unambiguously understand a diagram describing the radio or any other electronic device. As a consequence, engineers can discuss the radio using terms that are understood unambiguously by the parties involved. Moreover, the commonality of the language allows engineers to identify familiar patterns or modules … in a diagram of an unfamiliar device. Because the language is quantitative …, it is suitable for a quantitative analysis, including modeling.

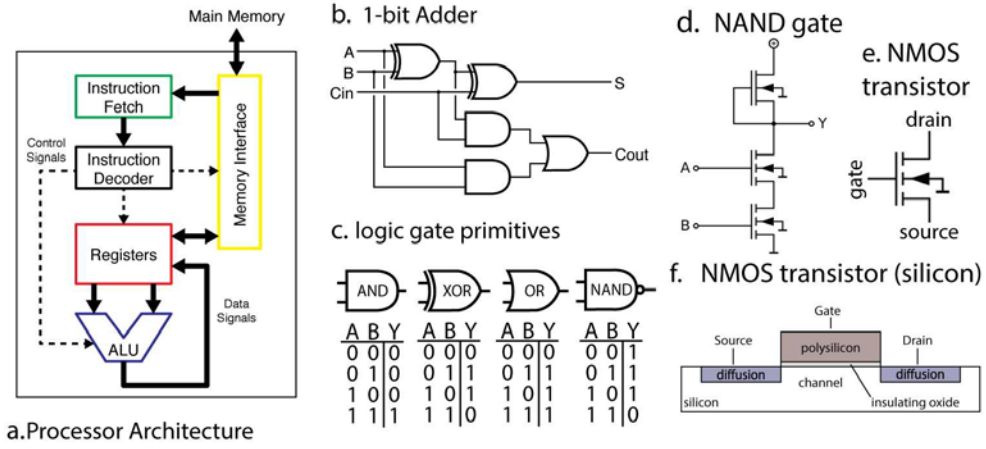
Could A Neuroscientist Understand A Microprocessor?

Jonas & Kording, PLoS 2017

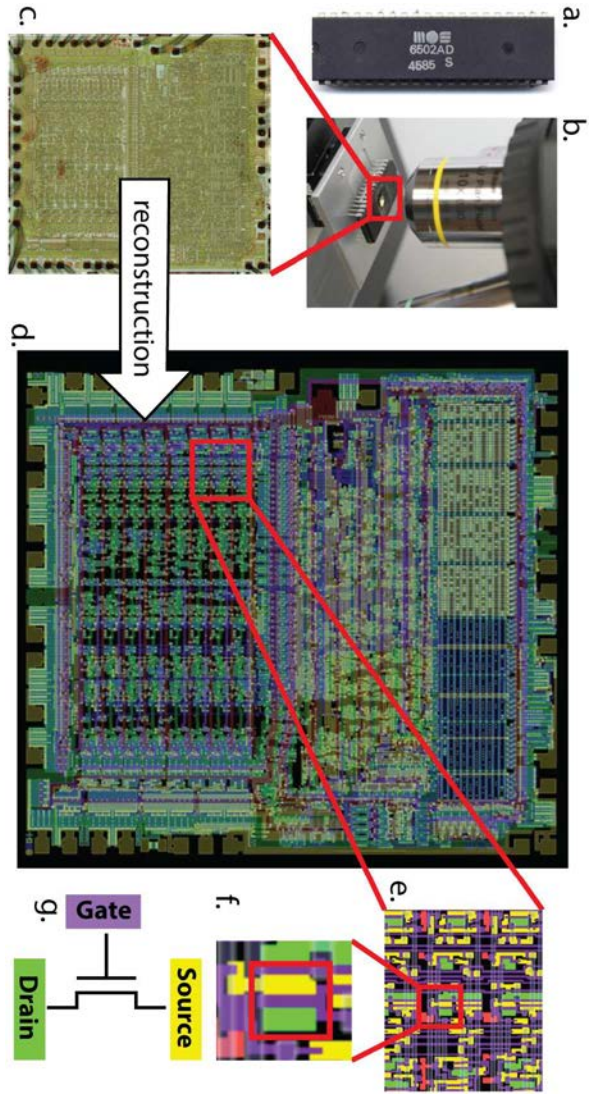


a. Donkey Kong (DK) b. Space Invaders (SI) c. Pitfall (PF)

Figure 1: ***Example behaviors.*** *We use three classical video games as example behaviors for our model organism – (**A**) Donkey Kong (1981), (**B**) Space Invaders (1978), and (**C**) Pitfall (1981).*



a.Processor Architecture



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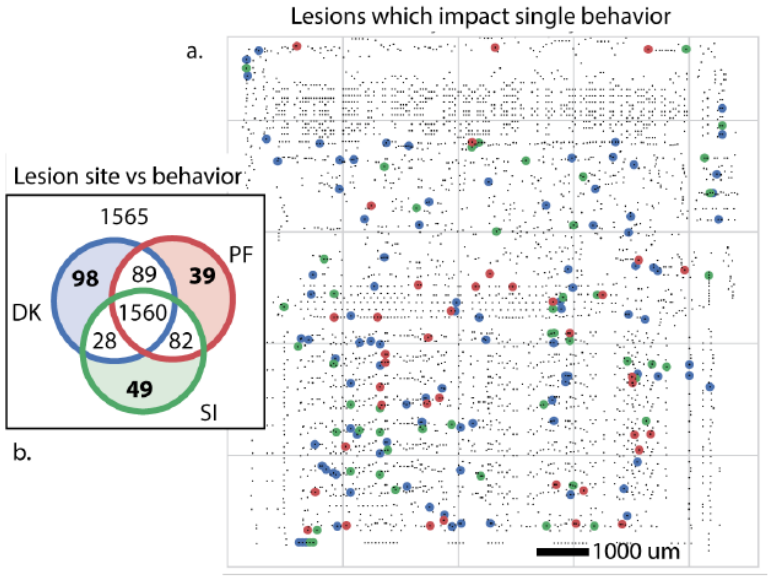


Figure 4: ***Lesioning every single transistor to identify function.*** *We identify transistors whose elimination disrupts behavior analogous to lethal alleles or lesioned brain areas. These are transistors whose elimination results in the processor failing to render the game. (**A**) Transistors which impact only one behavior, colored by behavior. (**B**) Breakdown of the impact of transistor lesion by behavioral state. The elimination of 1565 transistors have no impact, and 1560 inhibit all behaviors.*

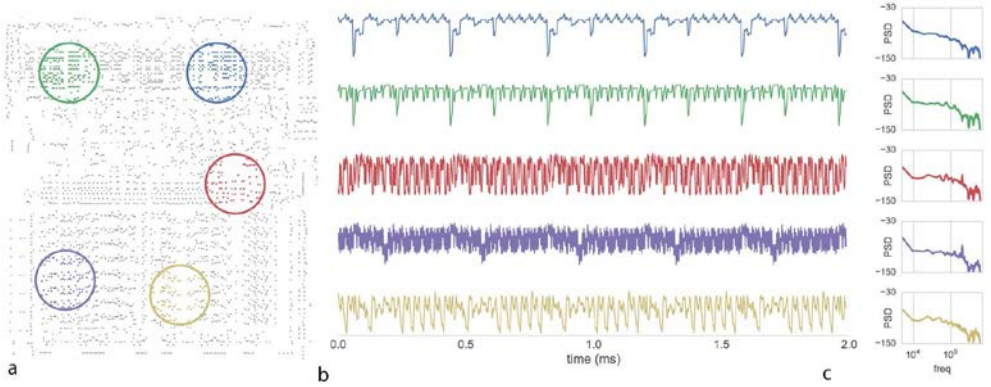


Fig 8. Examining local field potentials to understand network properties. We recorded from the processor during behavior DK. (**A**) Transistor switching is integrated and low-pass filtered over the indicated region. (**B**) local-field potential measurements from the indicated areas. (**C**) Spectral analysis of the indicated LFP regions identifies varying regionspecific oscillations or “rhythms”.

“In the chip we know that while the oscillations may reflect underlying periodicity of activity, the specific frequencies and locations are epiphenomena. They arise as an artifact of the computation and tell us little about the underlying flow of information. …

Moreover, the distribution of frequencies in the brain is often seen as indicative about the underlying biophysics. In our case, there is only one element, the transistor, and not multiple neurotransmitters. And yet, we see a similarly rich distribution of power in the frequency domain. …

Modeling the processor as a bunch of coupled oscillators, as is common in neuroscience, would make little sense.”

What Can(‘t) Functional Neuroimaging Tell Us?

For example:

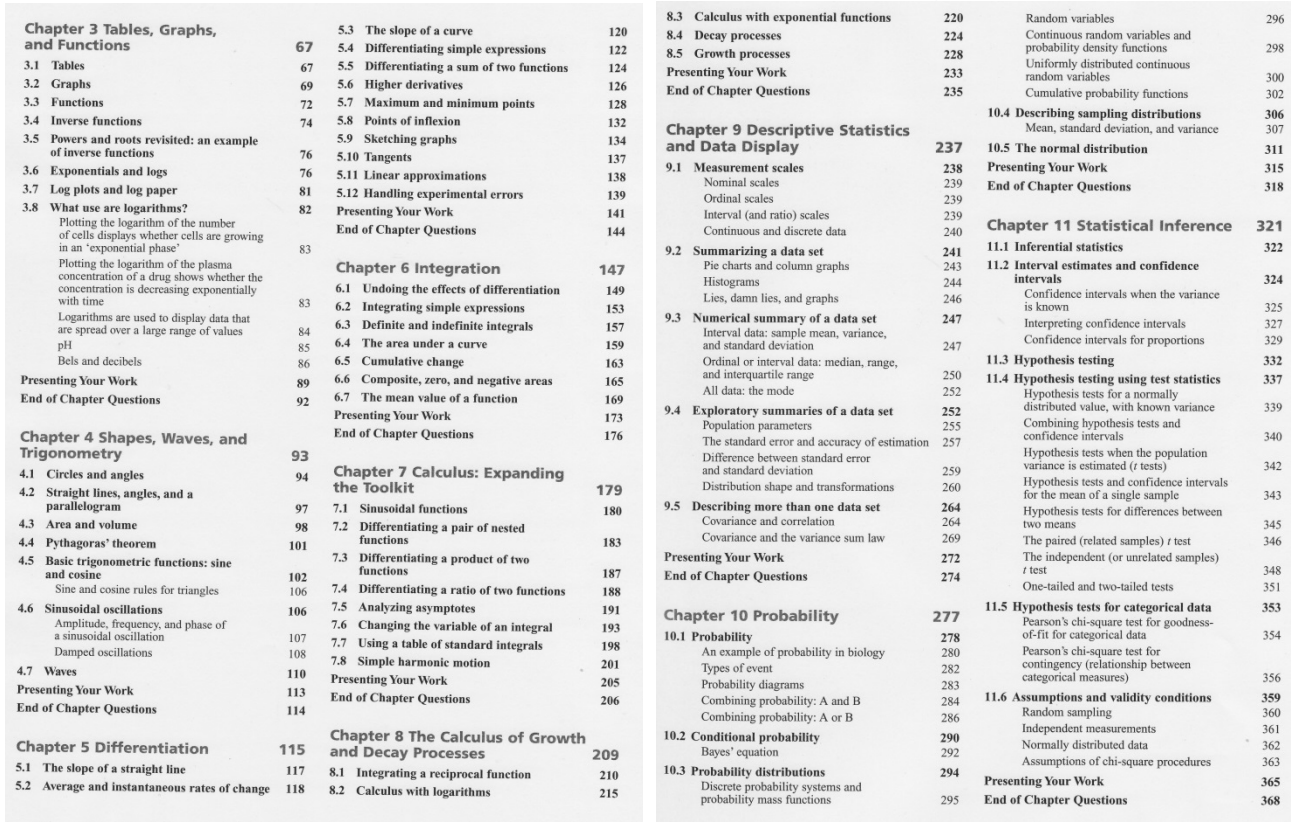
Henson, R:
“What can functional neuroimaging tell the experimental psychologist?”
QJEP 2005

Page, M:
“What can’t functional neuroimaging tell the cognitive psychologist?”
Cortex 2006

Special Issue:
“20 Years of fMRI – What has it done for Understanding Cognition?”
Perspect Psychol Sci 2013

Biologists Do It...
What About Cognitive Scientists?

Contents of “Mathematics for Biological Scientists”



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Biologists Do It…
What About Cognitive Scientists?

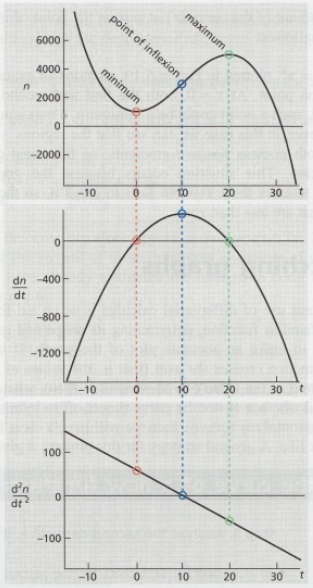

Figure 5.17
The variations of n, dn/dt, and d^2n/dt^2 with respect to time for the expressions describing the *E. coli* colony. The plot of n has a maximum and a minimum (for which the first derivative is zero) and a point of inflexion (for which the second derivative is zero).

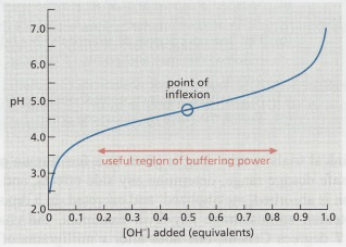

Figure 5.18
A plot of pH against concentration of added hydroxide ions for the acetate-acetic acid system. The system works best as a pH buffer when it is relatively insensitive to the amount of alkali that is added: this occurs near the point of inflexion in the titration curve, around pH 4.8.

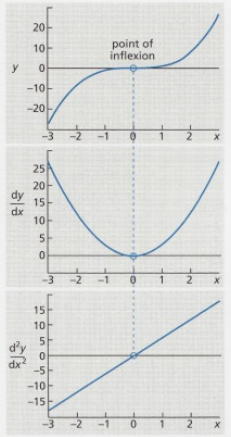

Figure 5.19
The graph of $y = x^3$ and its first two derivatives showing that $x = 0$ is a point of inflexion.

Aitken, Broadhurst, Hladky: “Mathematics for Biological Scientists”

MRC Cognition and Brain Sciences Unit

UNIVERSITY OF CAMBRIDGE

Thank you,
have a good evening