THE HONG KONG POLYTECHNIC UNIVERSITY
香港理工大學

Language, Cognition, and Neuroscience

LANGUAGE, BRAIN & COMPUTER.

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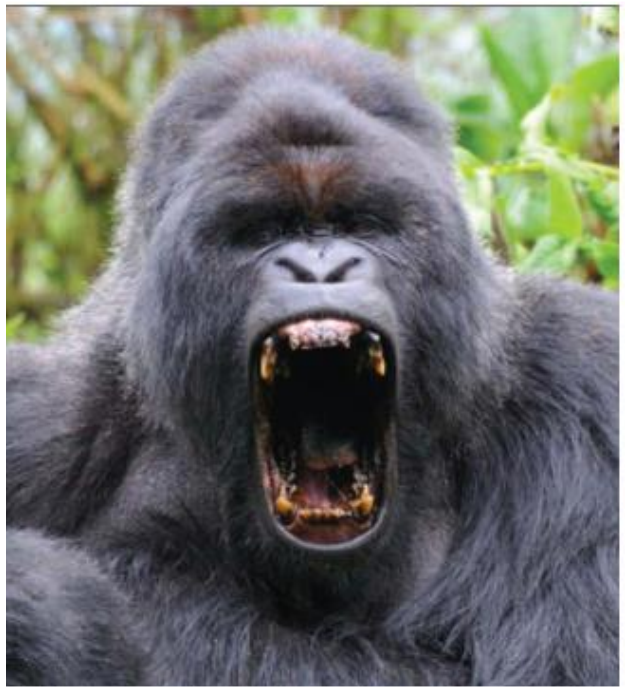
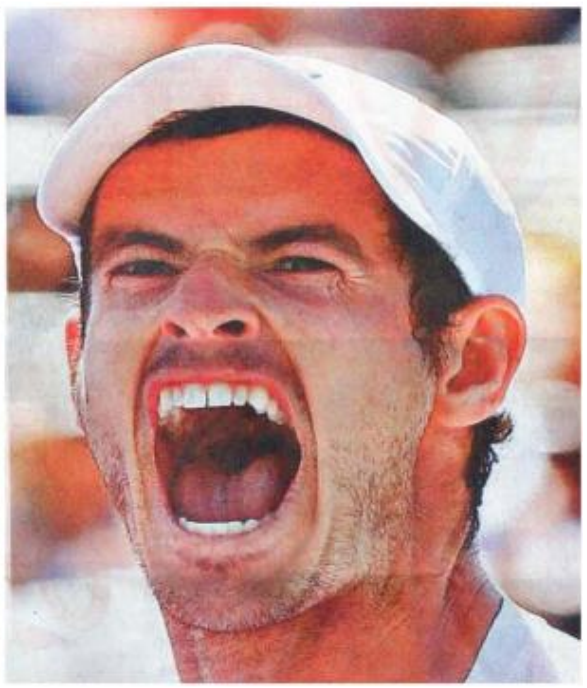
Chinese University of Hong Kong @ Shenzhen
presentation on 2019.05.21.

PDF available upon request.

LANGUAGE, BRAIN & COMPUTER.

Language emerged around 100,000 years ago, when the human brain evolved to its present form. This combination of language and brain enabled our ancestors to collaborate, share information, and change the world in ways unique to our species. The computer was invented only about 100 years ago, causing the world to change at a new and explosive pace. I will draw from the three disciplines: linguistics, cognitive neuroscience, and COMPUTER science, to show how they influence each other. While obsolescent computers may be disassembled or discarded, the challenge is much more complex and severe in the case of elderly people with brains that have become dysfunctional. This is an urgent and immense problem our society is now facing, that we must all join forces to solve.





Gorilla *Chimpanzee* *Homo*

Which two primates are the closest relatives?

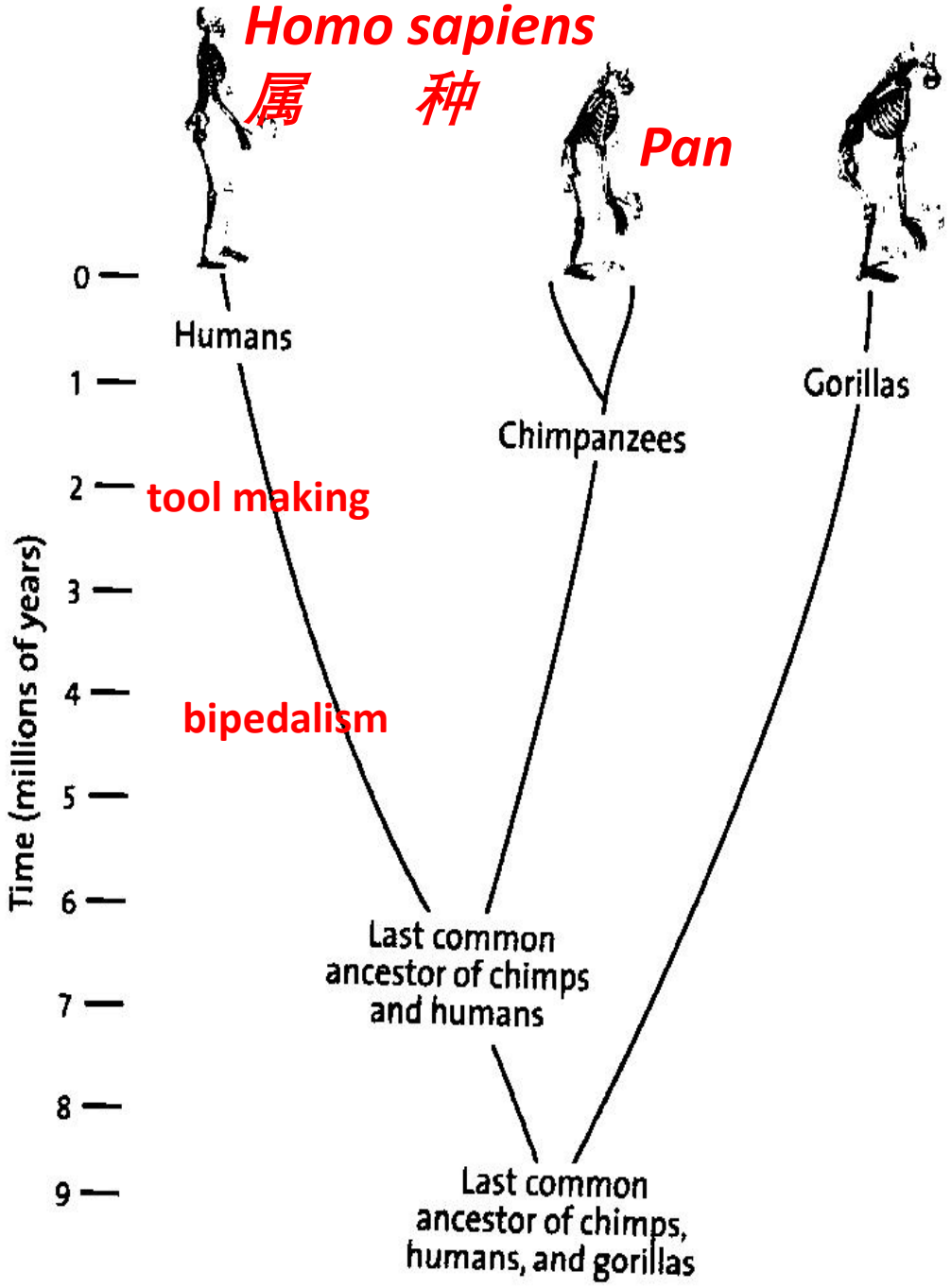
Lieberman, Daniel E. 2013:29.

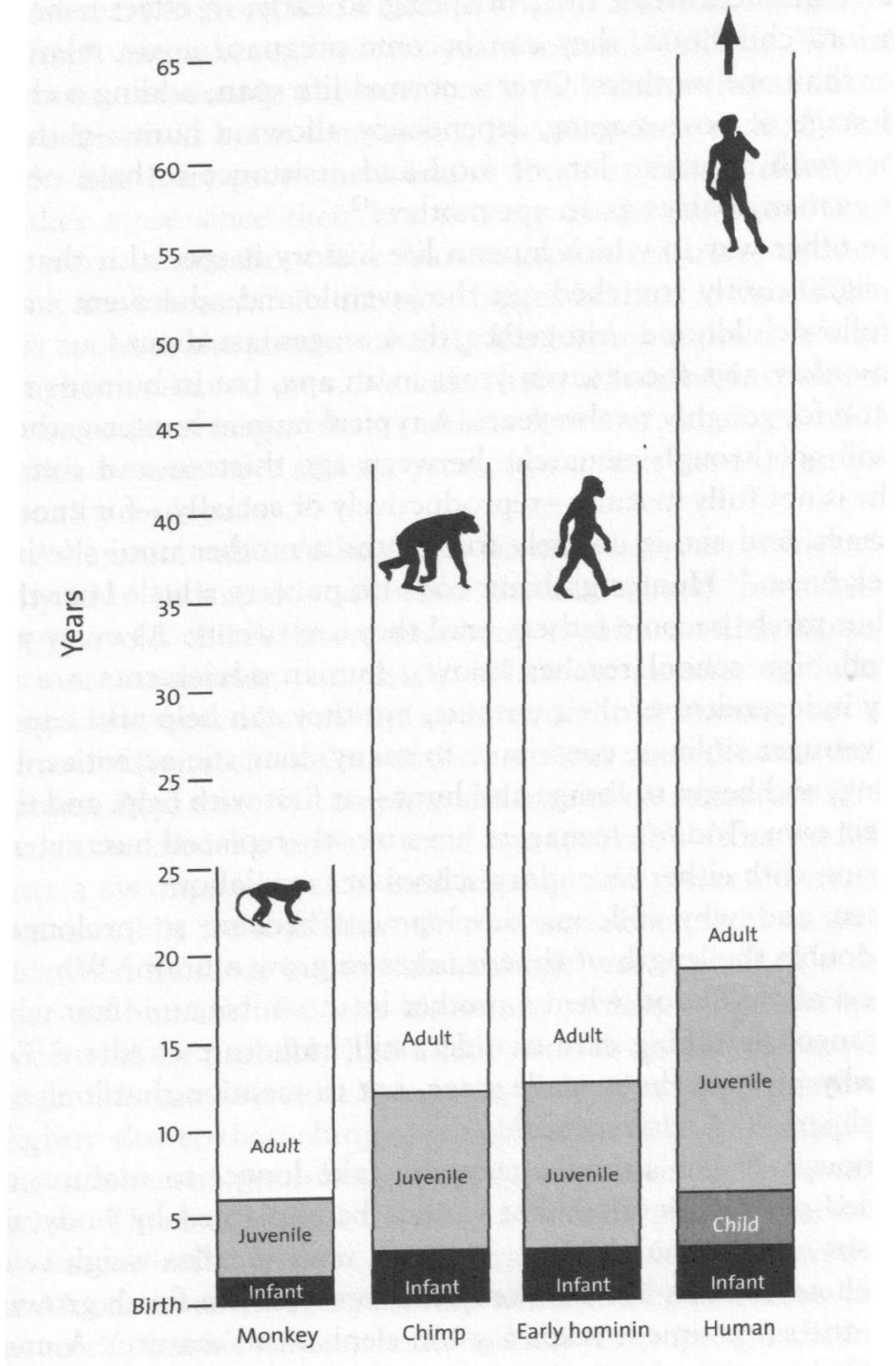
The Story of the Human Body: Evolution, health, & disease.

Pantheon.

Chimpanzees diverged into two species over a million years ago, separated by the Congo River.

The genus *Pan* divides into *troglodytes* & *paniscus*, with clear physical & social differences.

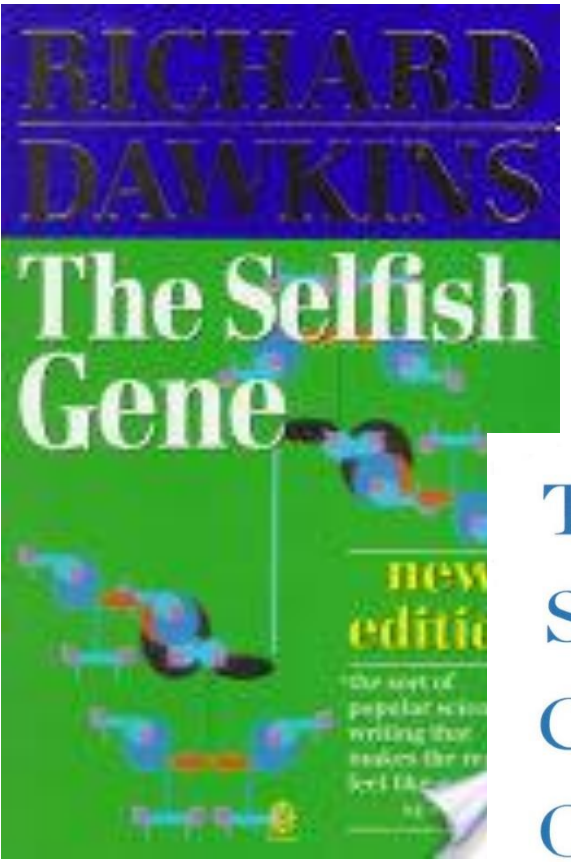




Lieberman, D.E. 2013. Figure 13.

***The Story of the Human Body: Evolution, health, & disease*. Pantheon.**

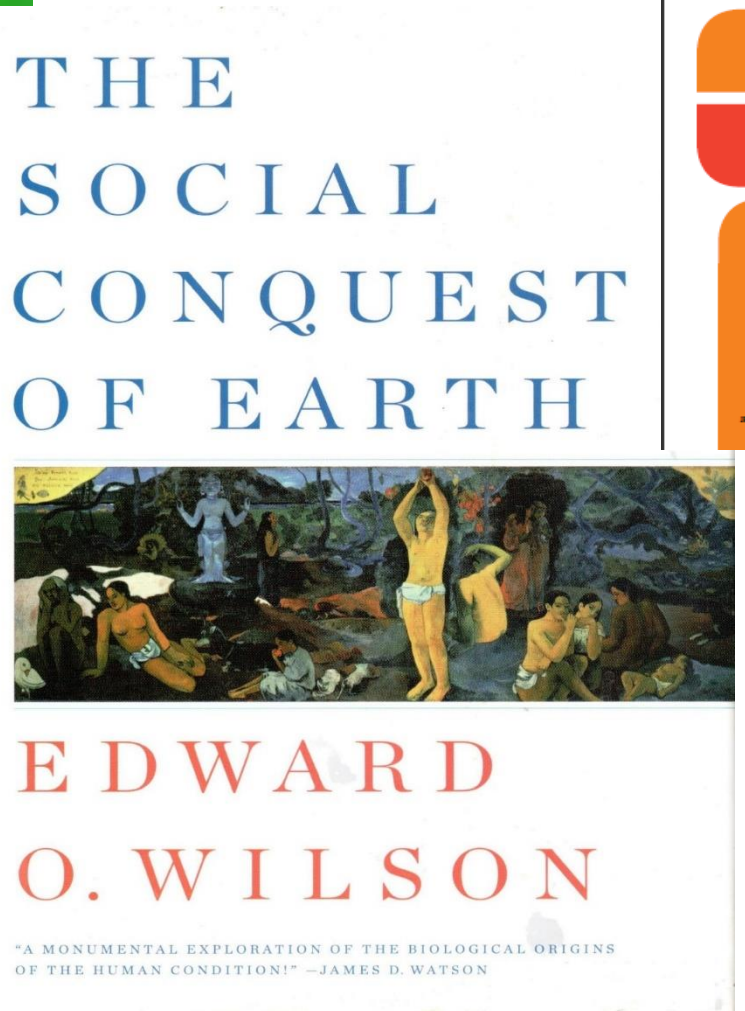
Humans have added a stage to their life-span, 'childhood', & prolonged the stage of 'juvenile'. These changes have greatly facilitated young ones to learn language & culture, as these become increasingly cumulative & complex. We have become 'Masters of the Planet' because we are uniquely driven by cultural evolution, which soon outpaced biological evolution by an ever larger margin.



Dawkins 1976

Nowak 2012

Wilson 2012



“物竞天择，
适者生存”

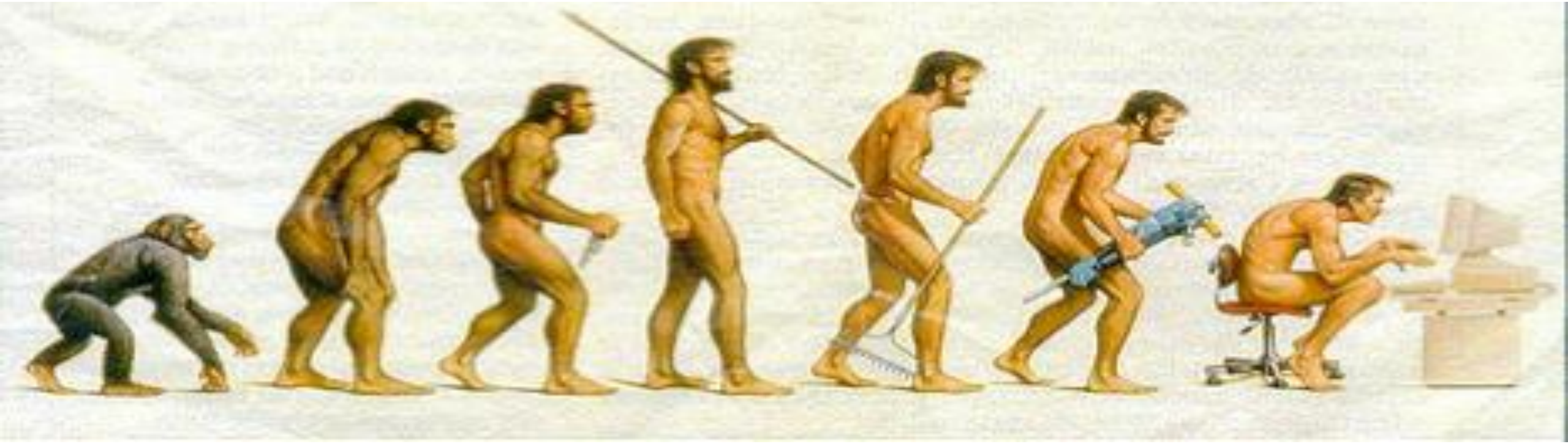
“Nature, red in tooth & claw …”

**演化并不只基于竞争，
合作也能让群体
更具有生存优势。**

很多种动物都有合作行为。可是因为人类有**语言**来表达复杂微妙的思想及协助配合动，所以人类合作的群体大小、合作的本质方式，就与其他动物有天壤之别。

Tool Use and Cooperation by Chimpanzees

Frans de Waal
Chimpanzee Politics
1998:194.



6 Mya	3.5+ Mya	2.8+ Mya	150+ Kya	1940+ C.E.
split from chimpanzees	*Australopithecus* bipedalism	genus *Homo* tool making	species *sapiens* Anatomically Modern Humans	electronic communication

蔡元培 1868 -1940

同是动物，*1928.*

为什么只有人类能不断的进步，能创造文化？

因为人类有历史，而别的动物没有。因为他们没有历史，不能够把过去的经验传说下去。

。。。

为什么只有人类能创造历史，而别的动物没有？

因为人类有**变化无穷的语言**。

荀子 *Xunzi [b.323 BCE] on the origin of words.*

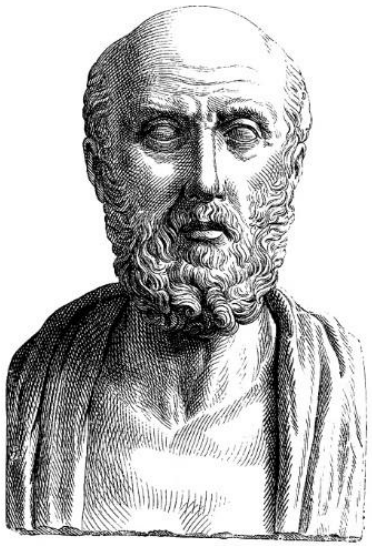
- **名无固宜**，约之以命，约定俗成谓之宜。
- **名无固实**，约之以命，约定俗成谓之实名。
- **名有固善**，径易而不拂，谓至善名。

- Words have no intrinsic correctness. The correctness is established by **convention**. When the convention is established and the custom formed, the words are then correct.
- Words have no intrinsic content. The content is given by convention. When the convention is established and the custom formed, the words then have content.
- Words have intrinsic appropriateness. Those which are direct and not misleading are appropriate words … to hear it and [thereby] understand it, that is the use of a word.

==========

Most of language, both vocabulary and grammar,
as is much of culture, is based on conventionalization, or **约定俗成**.

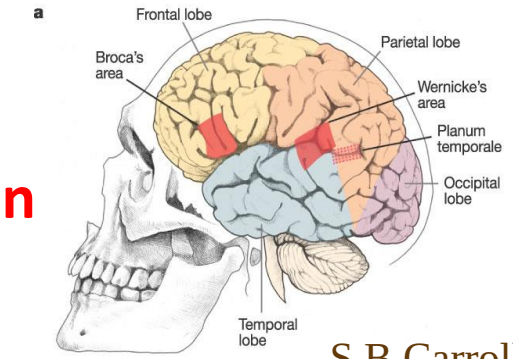
*"And men ought to know that **from nothing else … but from the brain** come joys, delights, laughter and sports, and sorrows, griefs, despondency, and lamentations. And by this, in an especial manner, we acquire wisdom and knowledge, and see and hear, and know what are foul and what are fair, what are bad and what are good, what are sweet, and what unsavory… And by the same organ we become mad and delirious, and fears and terrors assail us… All these things we endure from the brain, when it is not healthy … **In these ways I am of the opinion that the brain exercises the greatest power in the man**.*



***This is the interpreter to us of those things which emanate from the air, when it [the brain] happens to be in a sound state**."*

Hippocrates *quoted on p.509 of Syntactic Complexity. Givon & Shibatani, eds.2009. Emphasis added.*

Genetic basis of human brain evolution. 2008. Vallender, Eric, et al. *Trends in Neuroscience*.



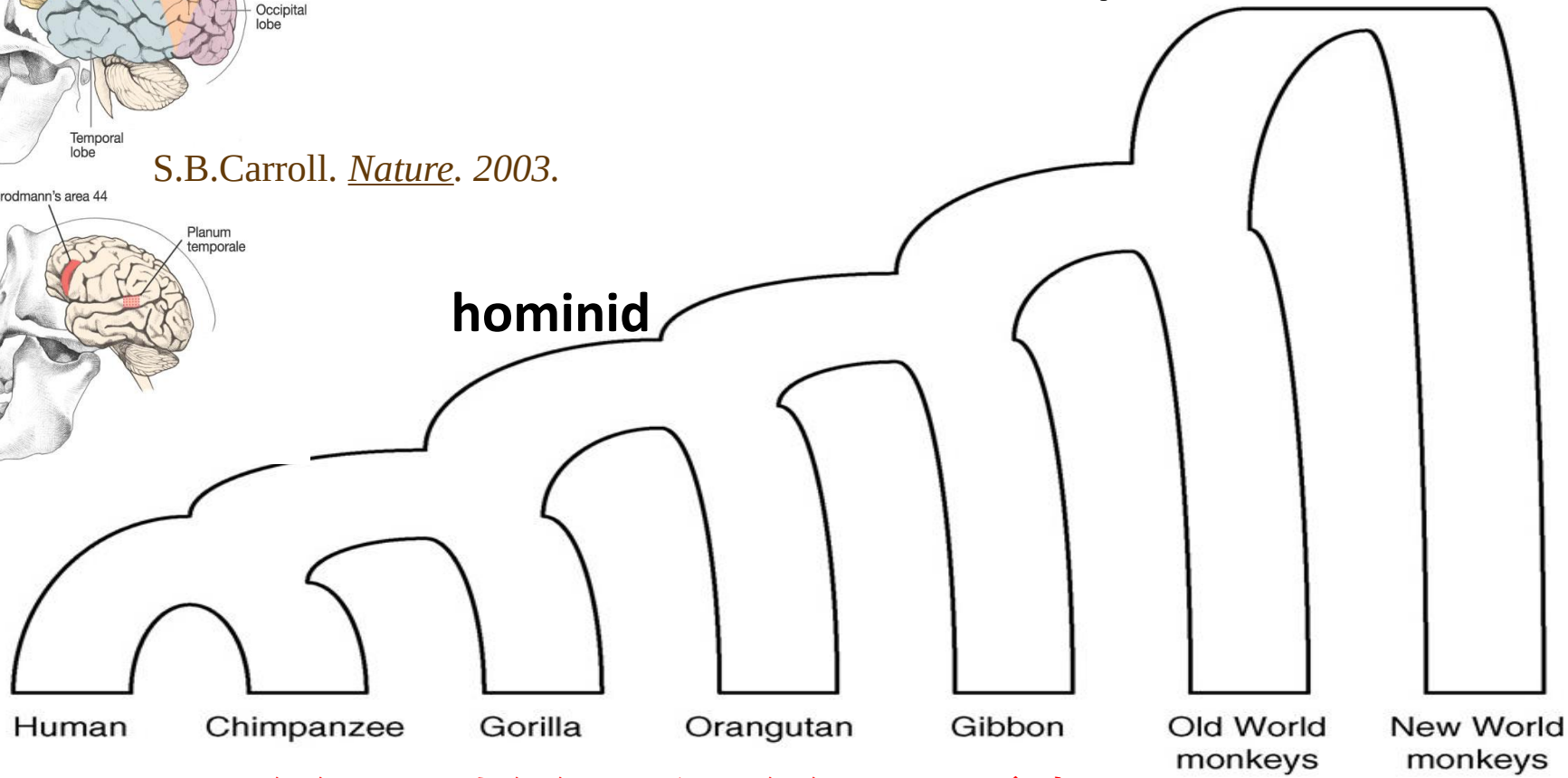
S.B.Carroll. *Nature*. *2003.*

hominin

南方古猿 Australopithecus
巧人 Homo habilis
直立人 Homo erectus
智人 Homo sapiens

primates 靈長類

hominid



	Human	Chimpanzee 黑猩猩	Gorilla 大猩猩	Orangutan 红毛猩猩	Gibbon 長臂猿	Old World monkeys	New World monkeys
Millions of years since last common ancestor with human	---	5–7	7–9	~14	~18	~25	35–40
Genetic difference from human	---	~1.2%	~1.6%	~3.1%	~4.0%	~6.5%	~11.5%
Brain volume in cm^3	1129–1685	230–415	400–565	300–400	70–152	33–205	4–123

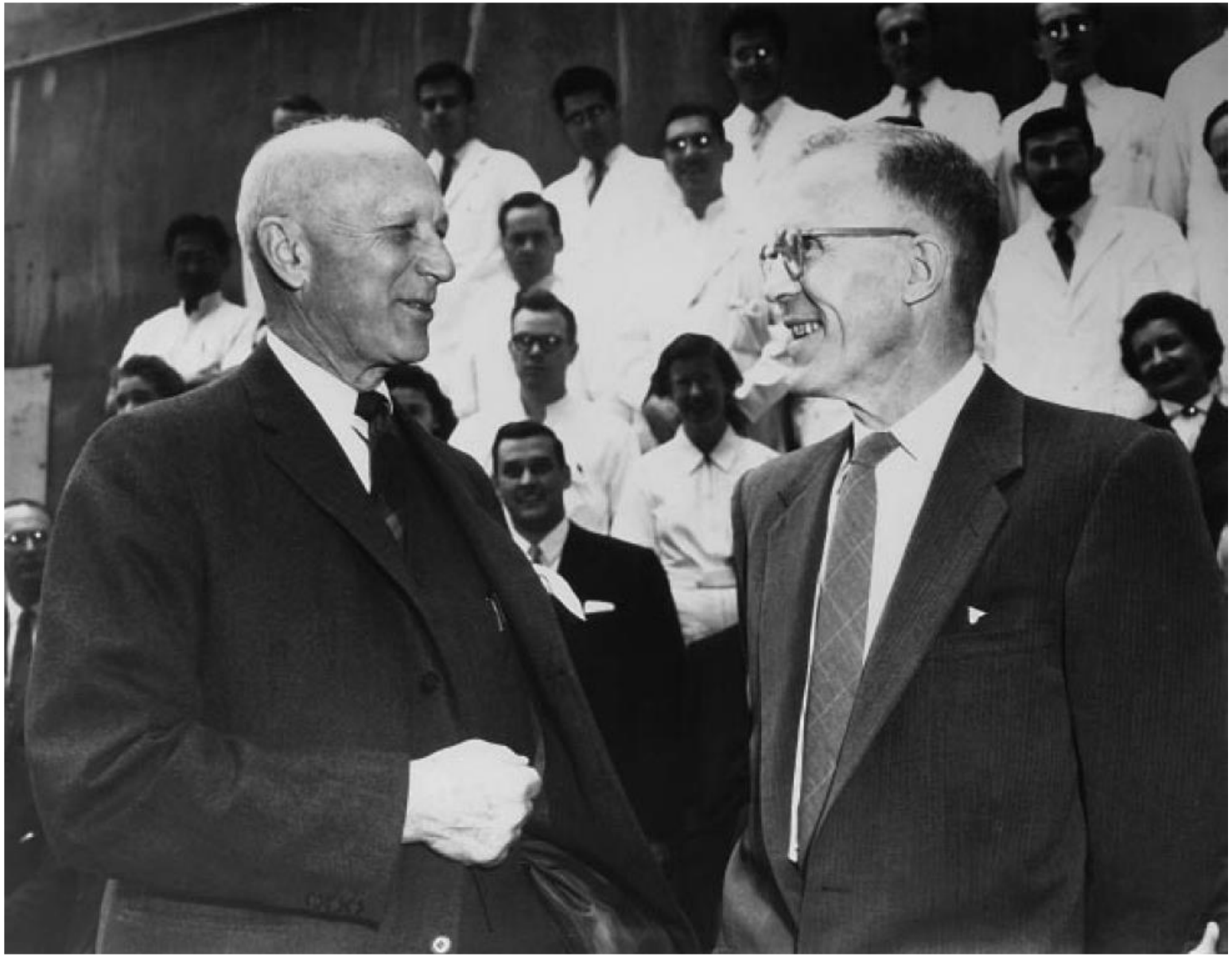
TRENDS in Neurosciences

Soemmering, S. T. 1791.

"Does use and exertion of mental power gradually change the material structure of the **brain**, just as we see, for example, that much used **muscles** become stronger? It is not improbable, although the scalpel cannot easily demonstrate this."

quoted in *The New Brain* by R.Restak.

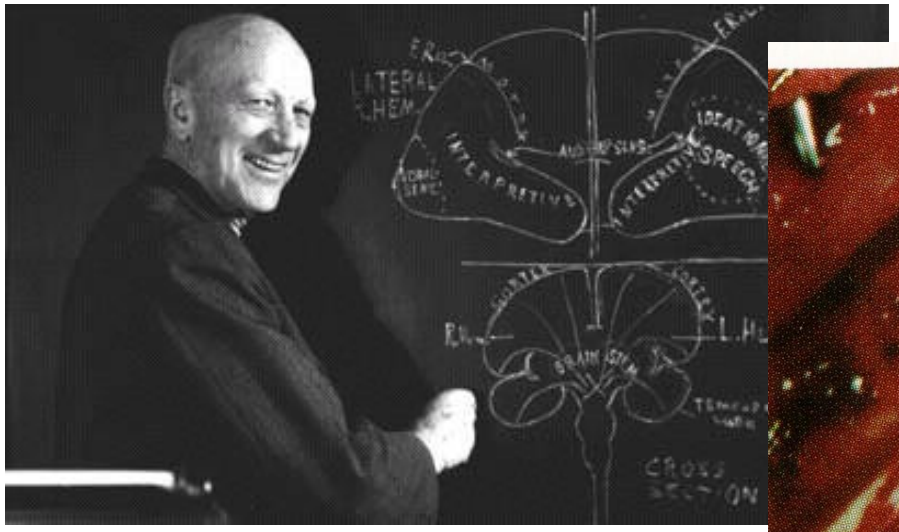
cf. 用进废退。

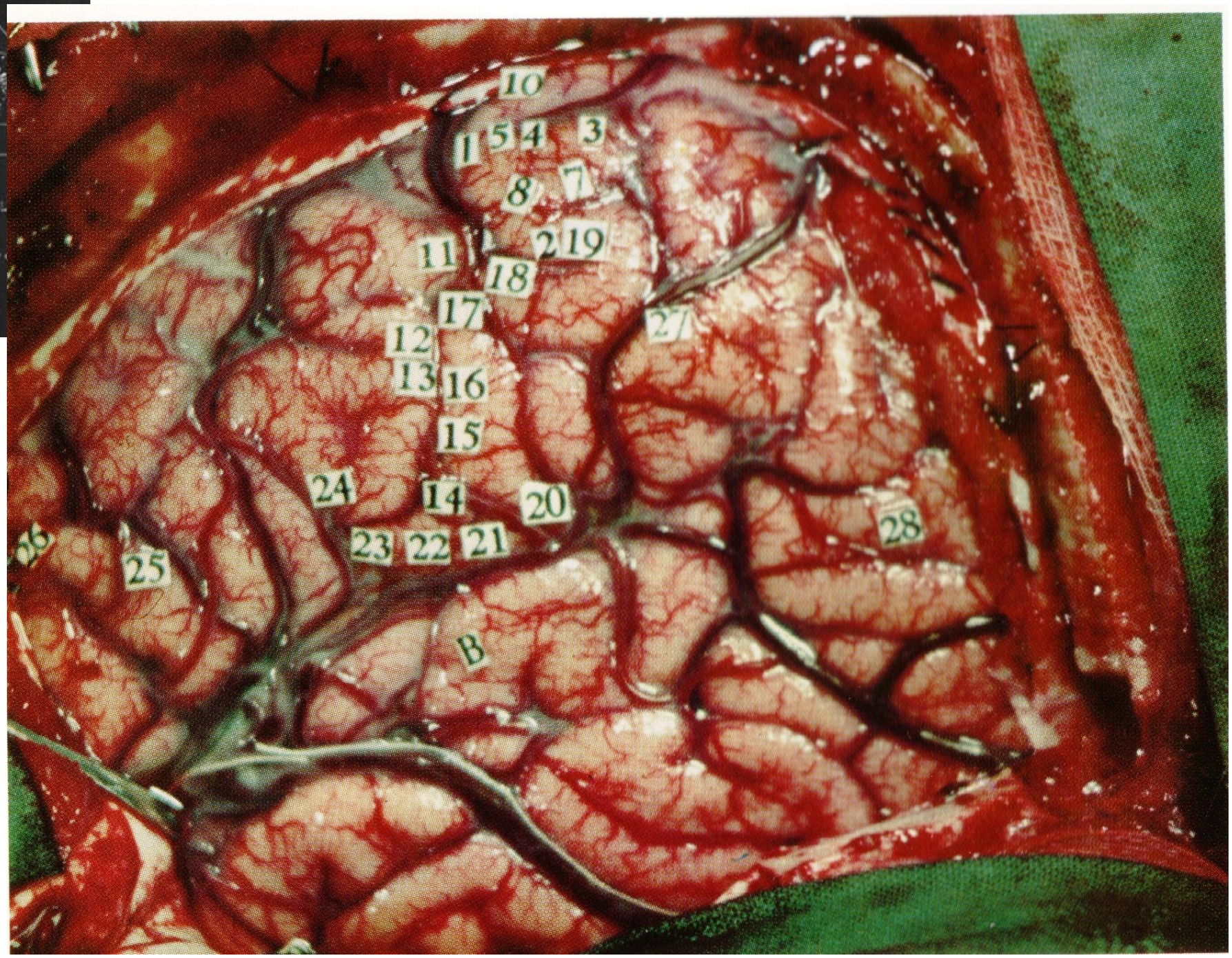


Penfield *(1891-1976)* & Hebb *(1904 –85)* in 1958 on the occasion of Hebb delivering the 24th Annual Hughlings Jackson lecture at the Montreal Neurological Institute.

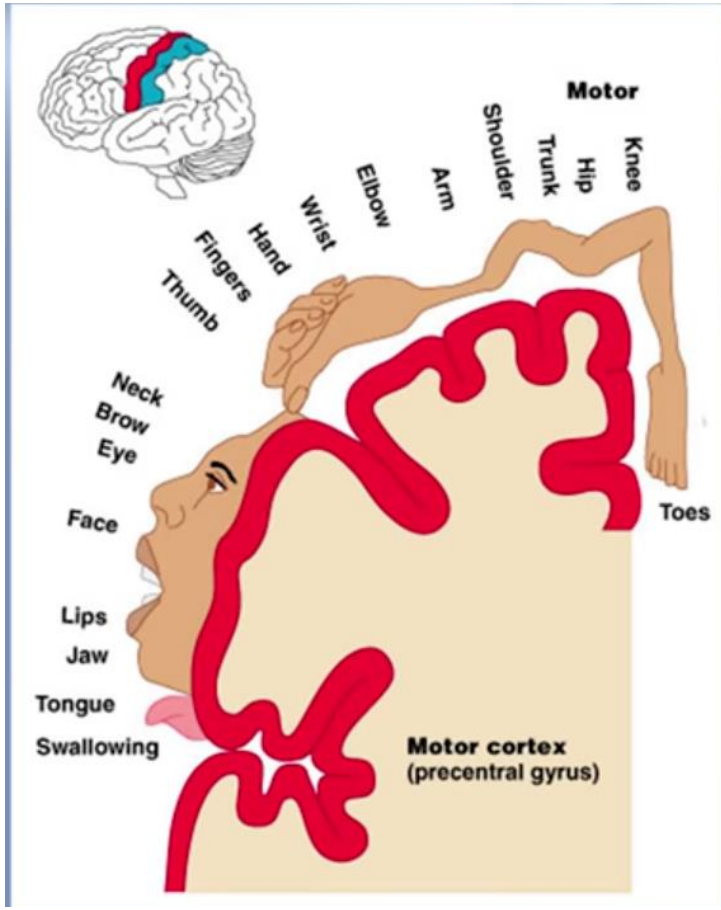
Milner, Brenda, Larry R. Squire. & Eric R. Kandel. 1998. "Cognitive Neuroscience & the Study of Memory." *Neuron* **20**: 445-468.

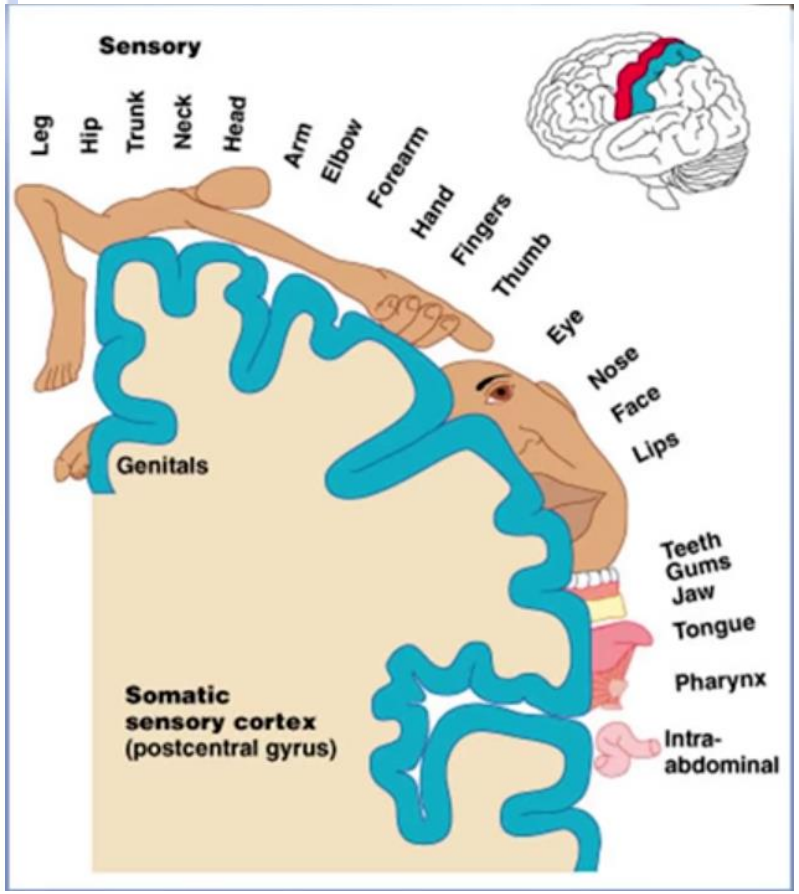
Hebb, Donald O. 1949. The organization of behaviour. John Wiley & Sons.
Penfield, Wilder, L. Roberts. 1959. Speech and Brain Mechanisms., Princeton University Press.





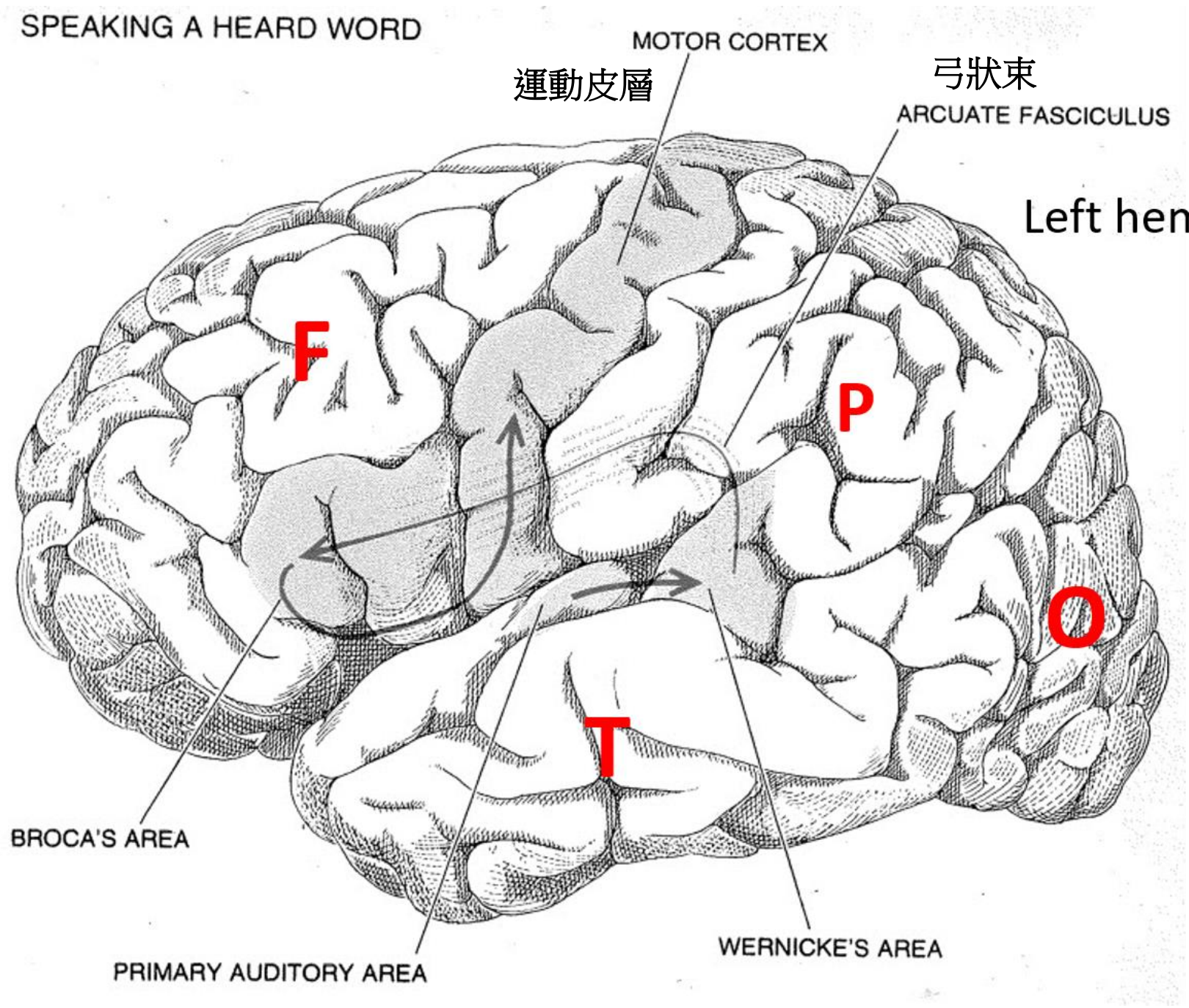
Penfield, W. & L. Roberts. 1959. Speech and Brain Mechanisms. Princeton University Press.





Penfield, W. & L. Roberts. 1959. Speech & Brain Mechanisms. Princeton University Press

Penfield, W. 1965. Conditioning the uncommitted cortex for language learning. ***Brain*** 88.787-98.



Reprinted in 王士元 2008.
語言湧現: 發展與演化.
中央研究院 語言學研究所.

Left hemisphere & its four lobes:

Frontal, 額葉
Parietal, 頂葉
Temporal, 顳葉
Occipital. 枕葉

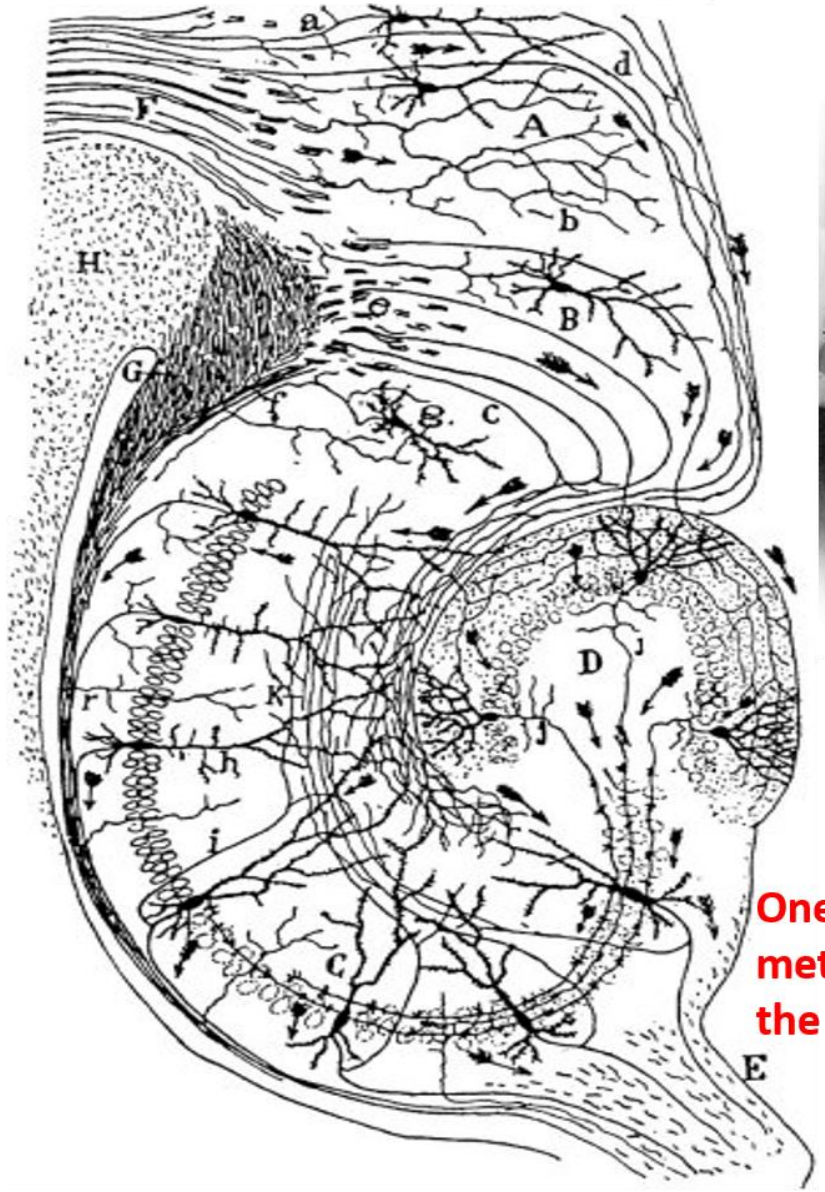
Geschwind, Norman. 1979.

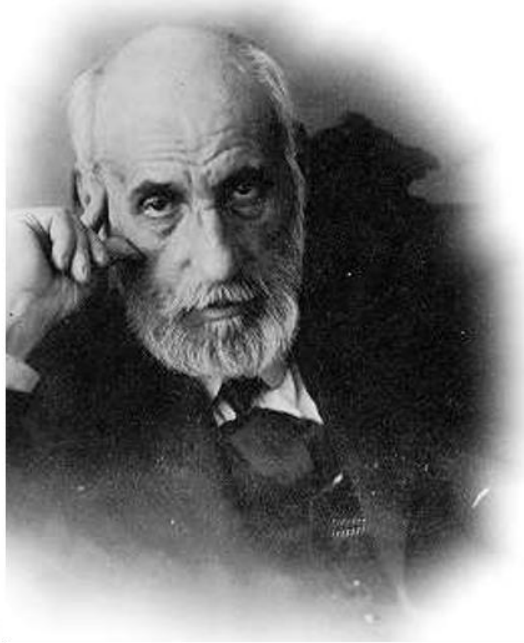
Specializations of the human brain.

Scientific American 241.158-68.

Ramon Santiago y Cajal

1852-1934. Nobel Prize 1906.





One of Cajal's numerous meticulous drawings of the brain's neural circuits.

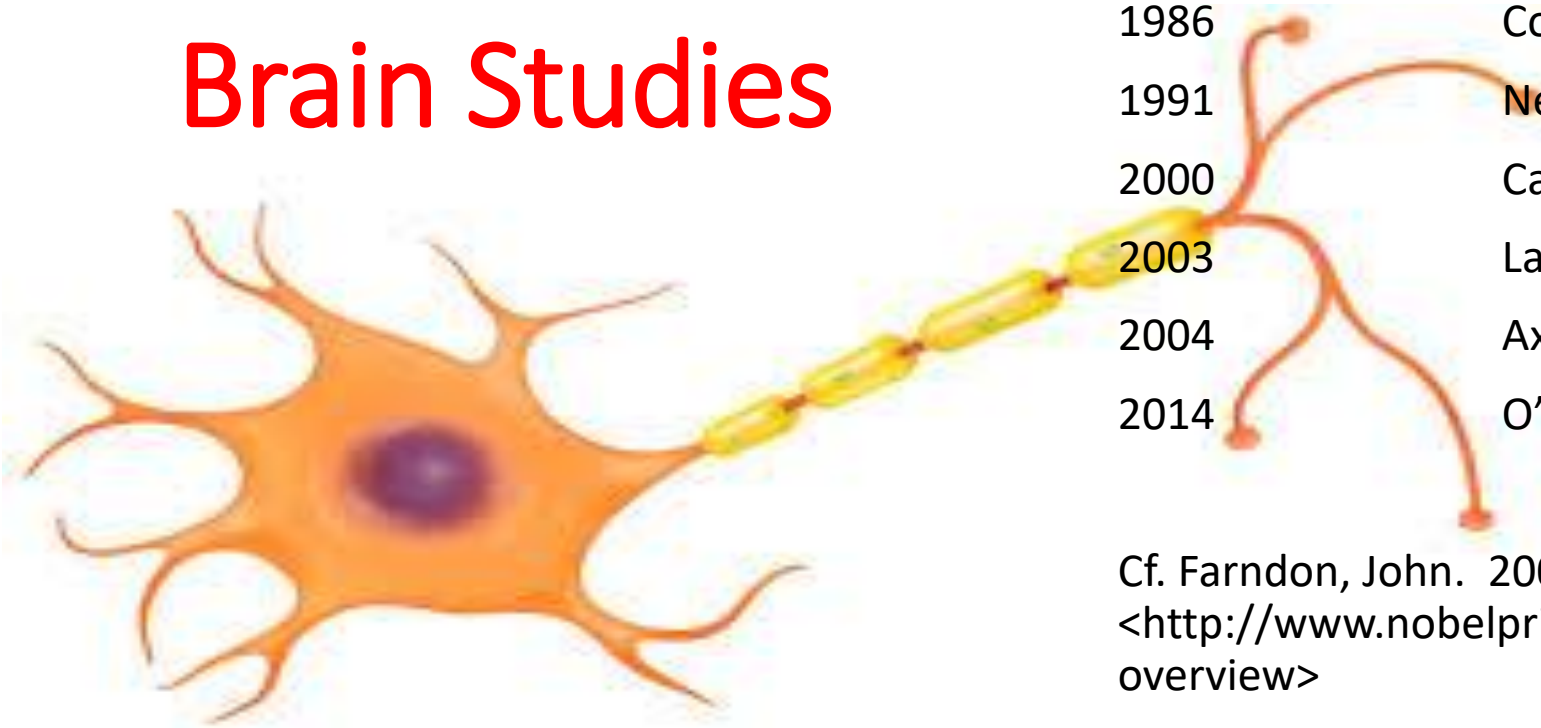
Nobel Prizes

in Physiology or Medicine

for

Brain Studies

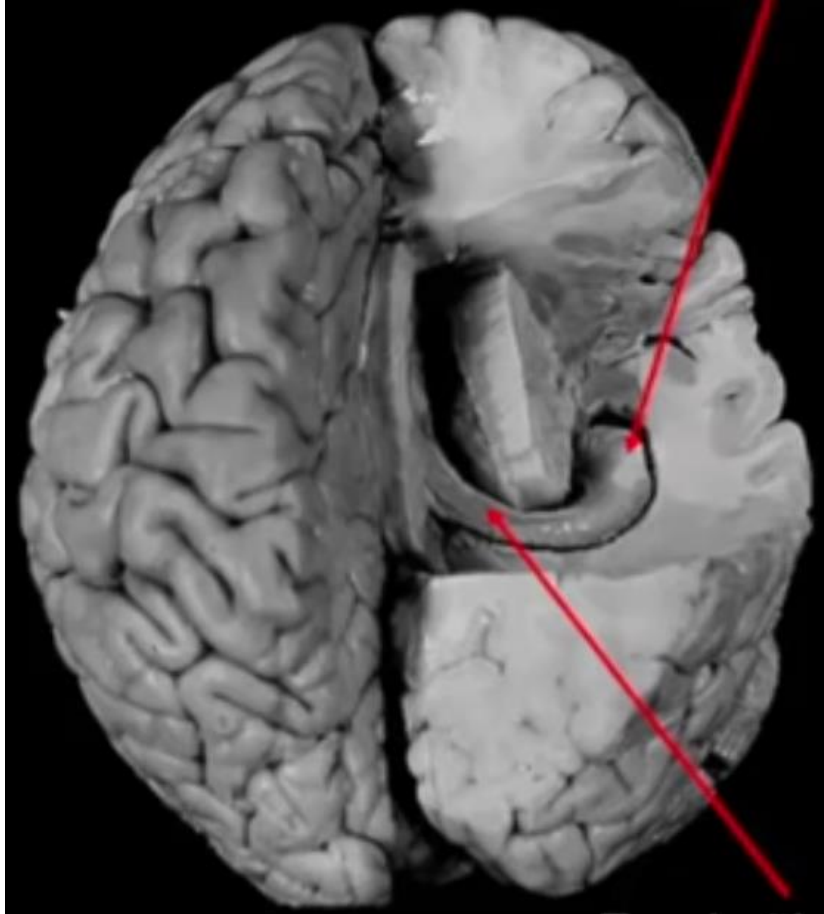
1906	Golgi & Cajal
1932	Sherrington & Adrian
1936	Dale & Loewi
1944	Erlanger & Gasser
1961	Bekesy
1963	Hodgkin, Huxley, & Eccles
1970	Katz, Von Euler, & Axelrod
1981	Sperry, Hubel & Wiesel
1986	Cohen & Montalcicni
1991	Nehr & Sakmann
2000	Carlsson, Greengard, Kandel
2003	Lauterbur & Mansfield
2004	Axel & Buck
2014	O'Keefe, Moser, & Moser



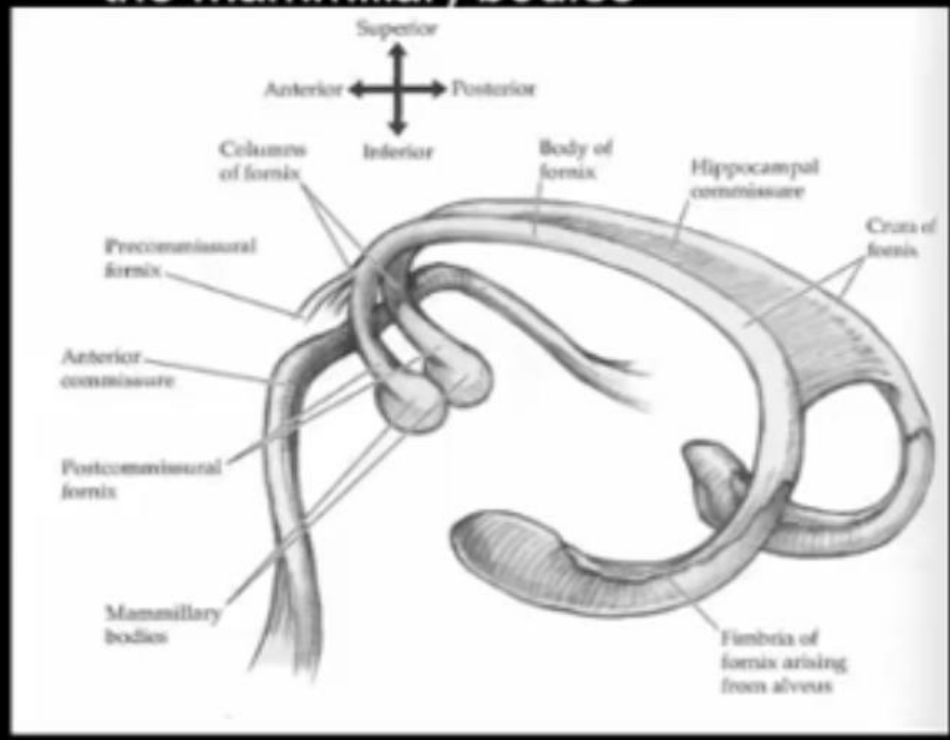
Cf. Farndon, John. 2009. Nerve signaling: tracing the wiring of life. <http://www.nobelprize.org/educational/medicine/nerve_signaling/overview>

Hippocampus

Hippocampus



The fornix connects the hippocampus to the mammillary bodies



Fornix (the axons of the hippocampal neurons)

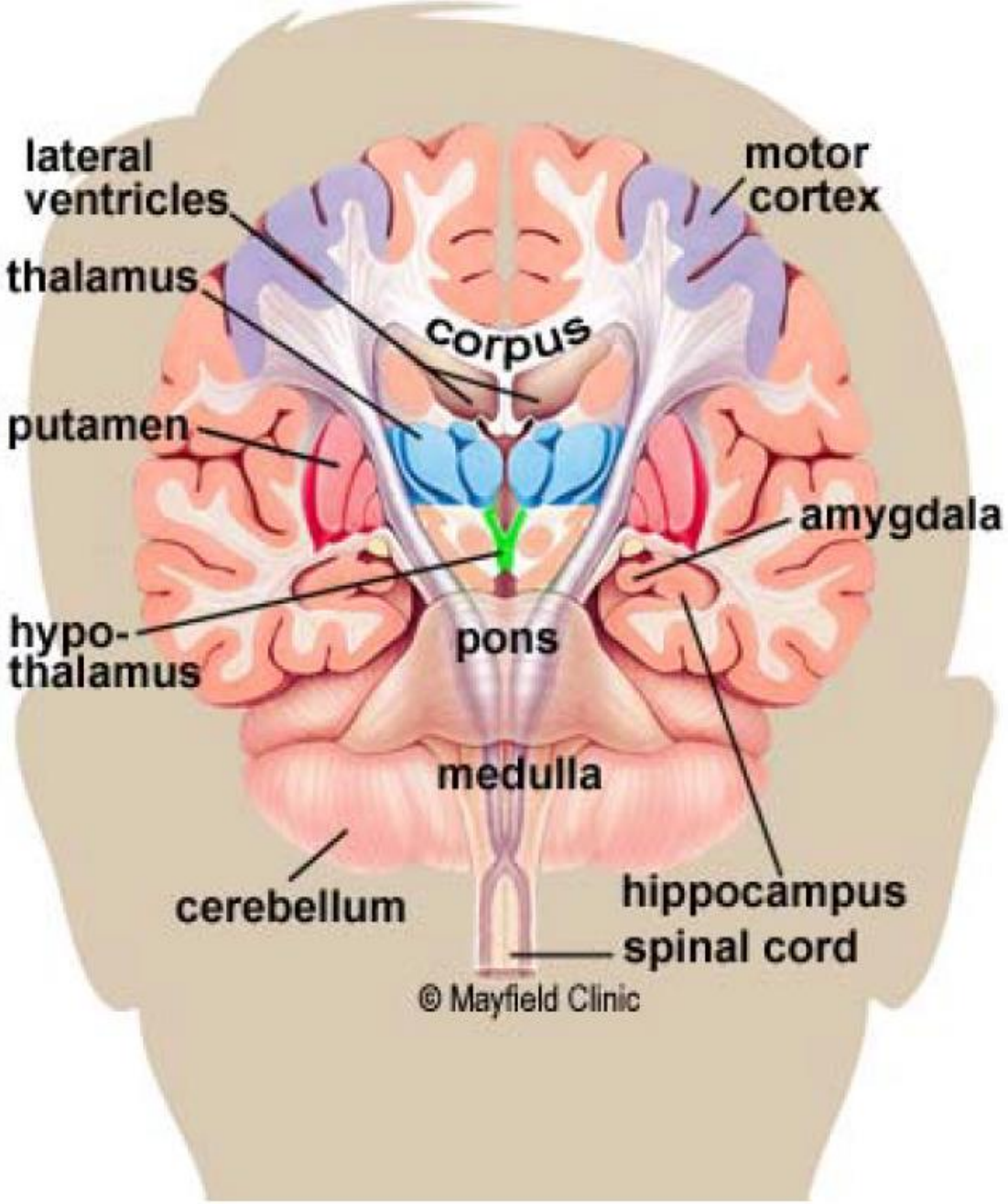
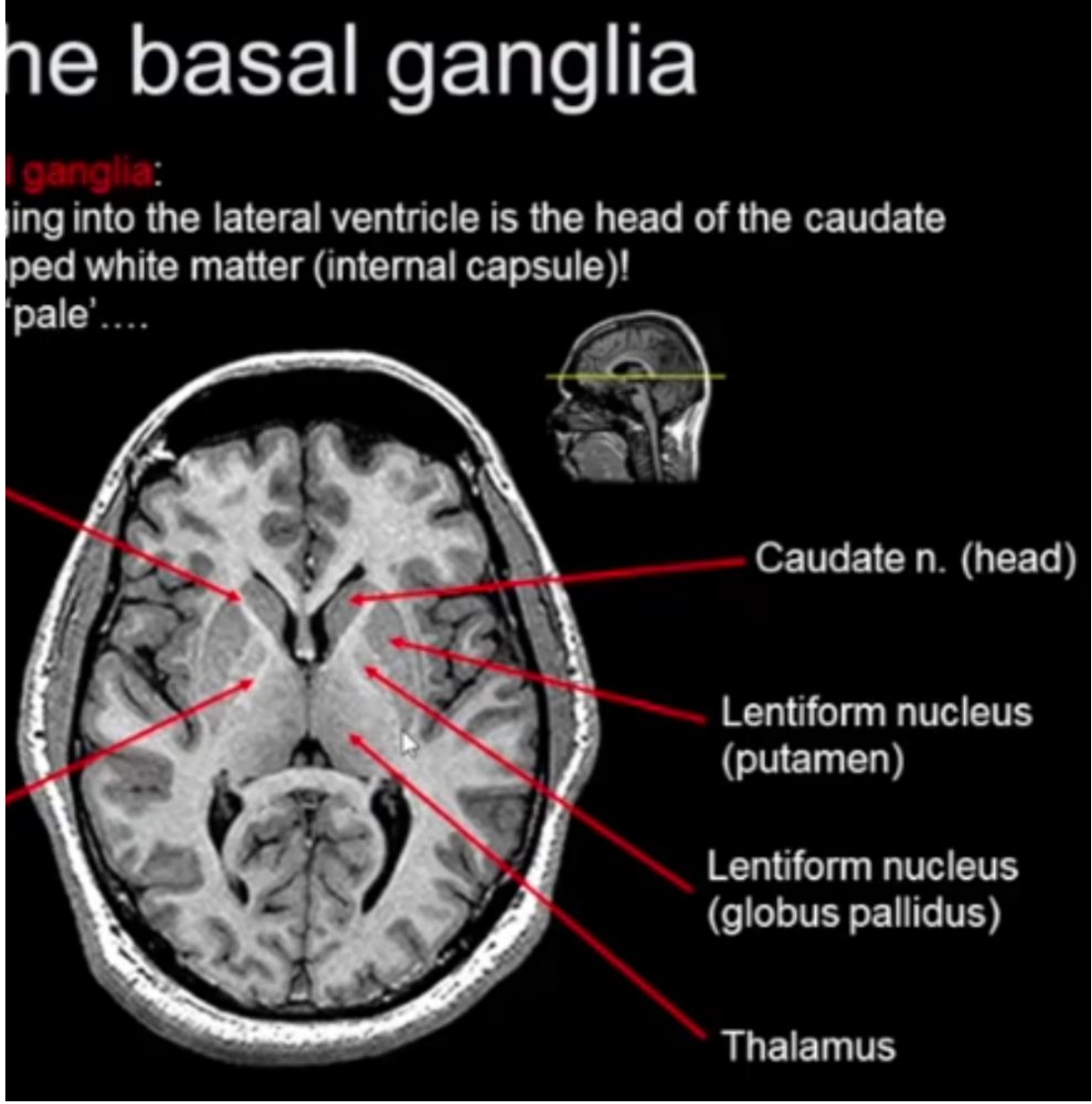
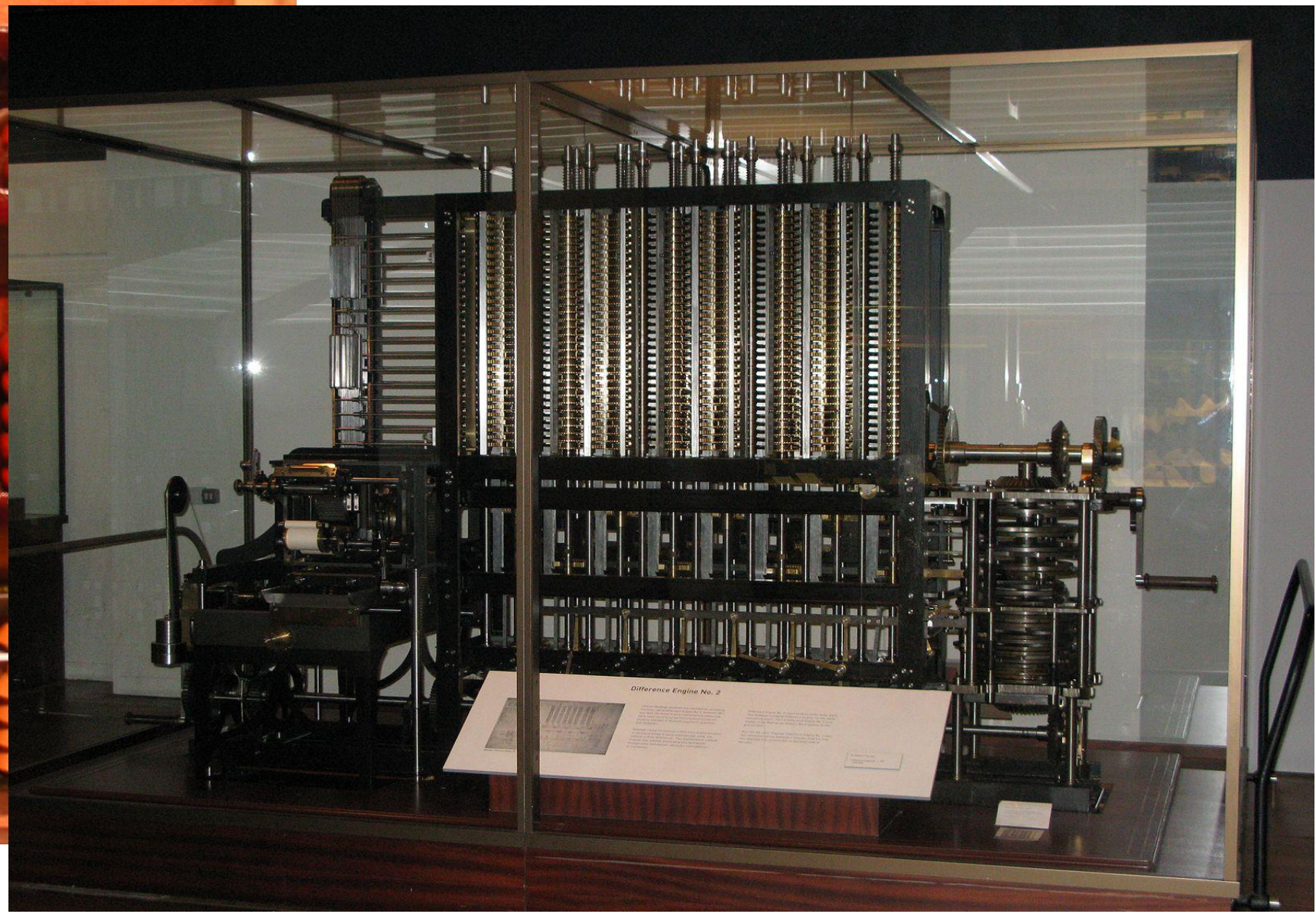


Figure 5. Coronal cross-section showing the basal ganglia.

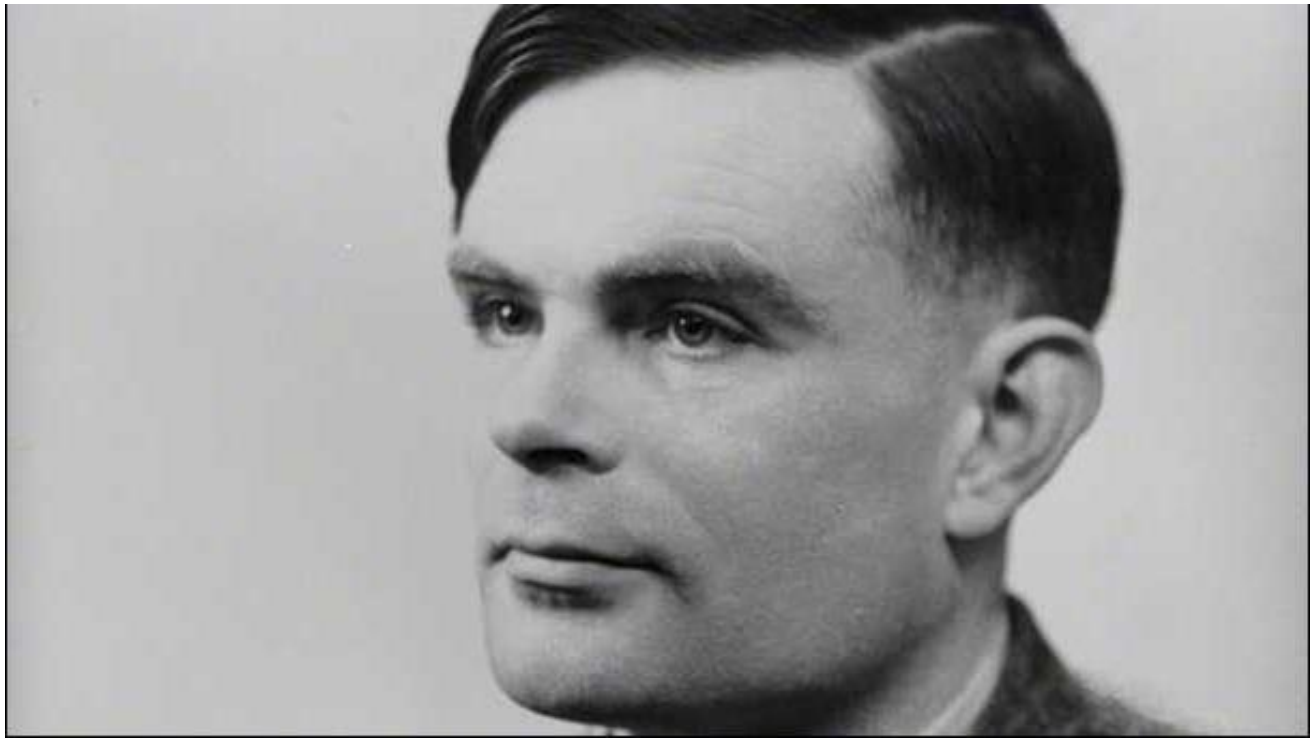


2 views of the basal ganglia.



Charles Babbage announced his invention in 1822 in a paper to the *Royal Astronomical Society* entitled "Note on the application of machinery to the computation of astronomical and mathematical tables".

John von Neumann
1903 - 1957.



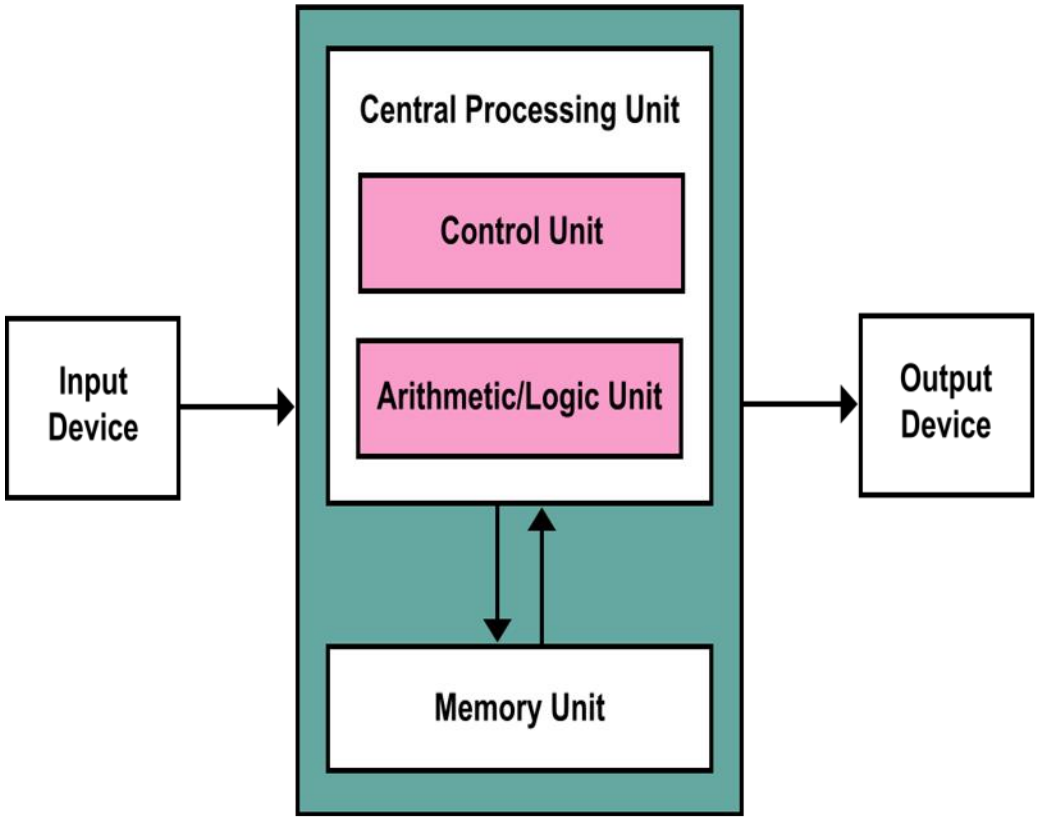
Alan M. Turing
1912—1954.
The Imitation Game is a 2014 film based on the biography *Alan Turing: The Enigma* by Andrew Hodges.

* **Turing, Alan M**. 1936. On Computable Numbers, with an Application to the Entscheidungsproblem, *Proceedings London Mathematical Society* **42:** 230–265.
* ---. 1938. --- A correction“, *Proceedings London Mathematical Society* **43:** 544–546.
* ---. 1945. Proposals for Development in the Mathematics Division of an **Automatic Computing Engine** (ACE),” presented to the National Physical Laboratory, UK. Reprinted as ComSci 57, 1972.
* ---. 1950. **Computing machinery and intelligence**." *Mind* **59**: 433-460.

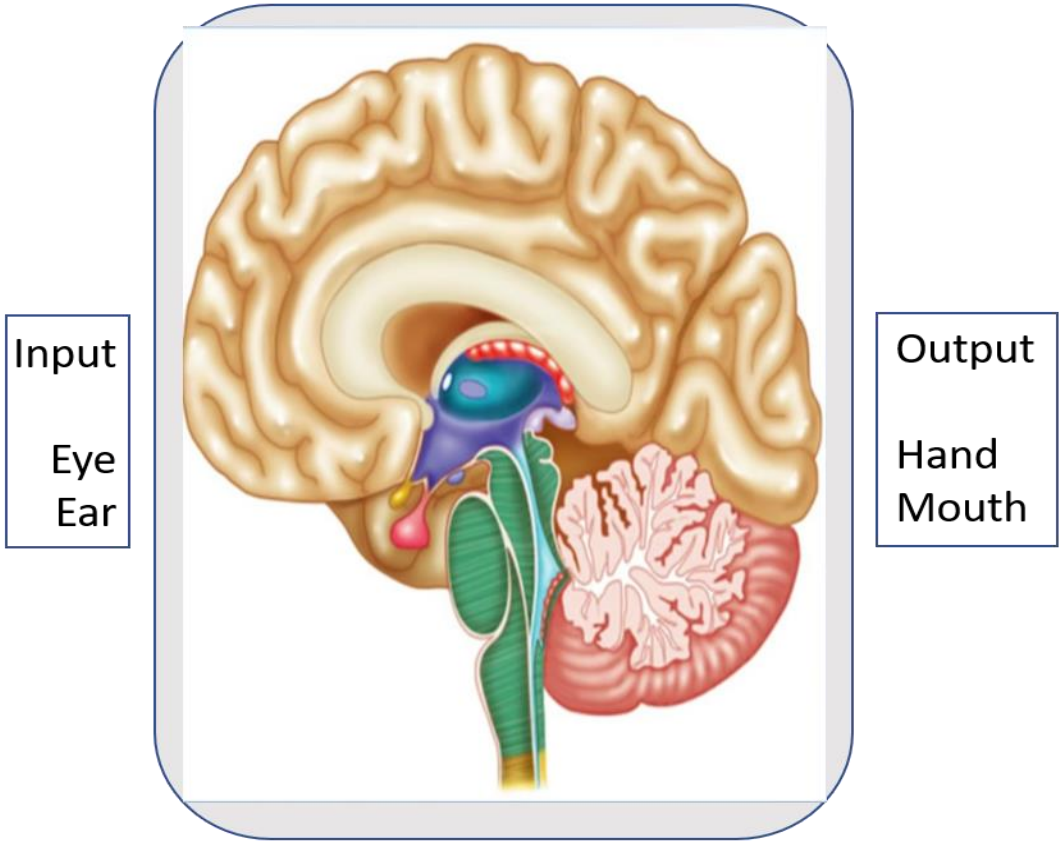
* **Neumann, John von**. 1945. First Draft of a Report on the EDVAC. See also Godfrey M.D. & D.F. Hendry. 1993. The Computer as von Neumann Planned It. *IEEE Annals of the History of Computing* 15: 11-21.
* ---. 1958/2000. **The Computer and the Brain**. Yale University Press. The reprinted version of 2000 has a substantive *Foreword* by Paul & Patricia Churchland of the University of California at San Diego.

THE COMPUTER & THE BRAIN

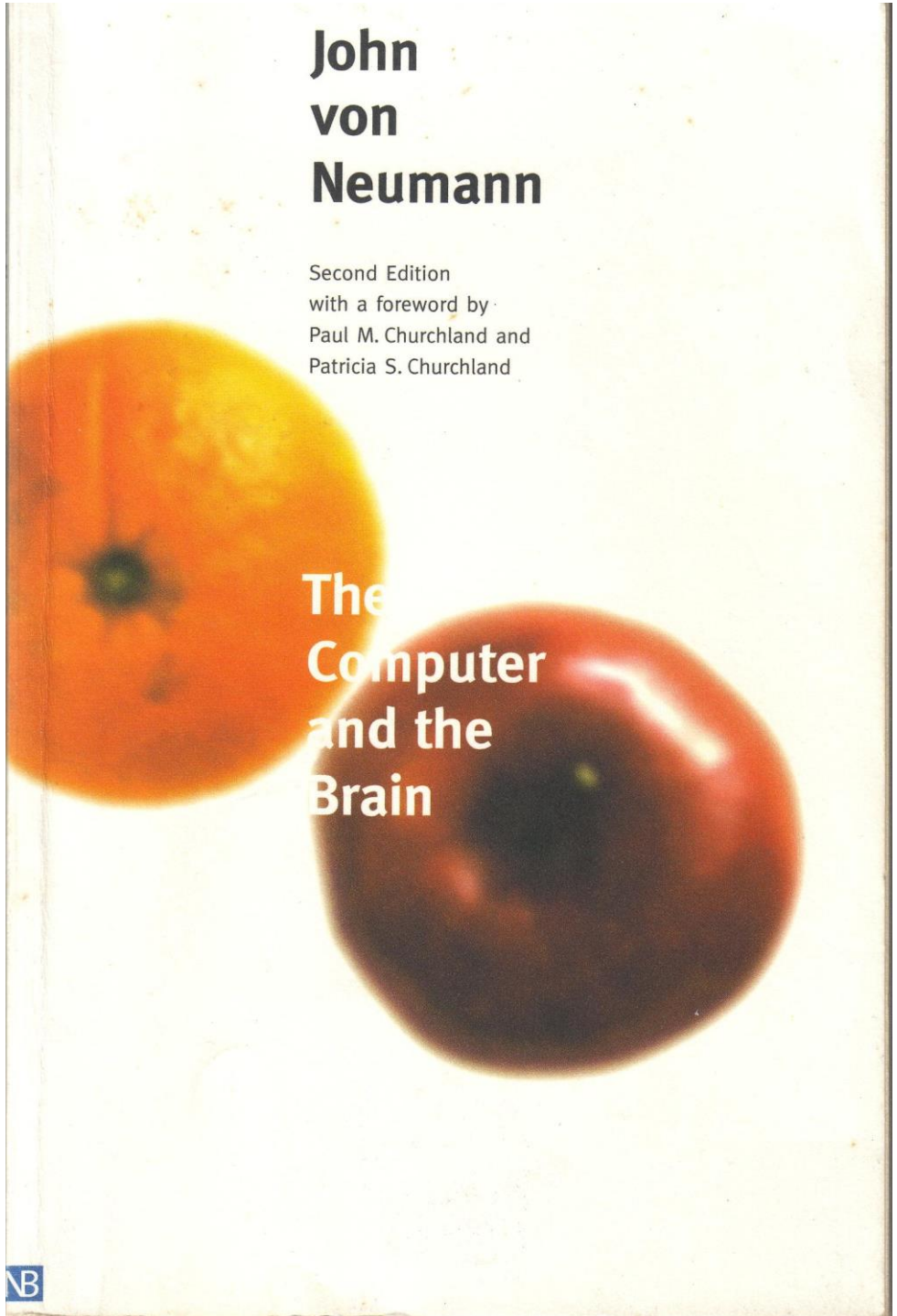
The Artificial & The Natural



Architecture by Von **Neumann**



Architecture by Evolution



Churchland, Paul & Patricia. 2000. Foreword to 2nd edition of *The Computer and the Brain*.
1st edition 1958. Yale University Press.

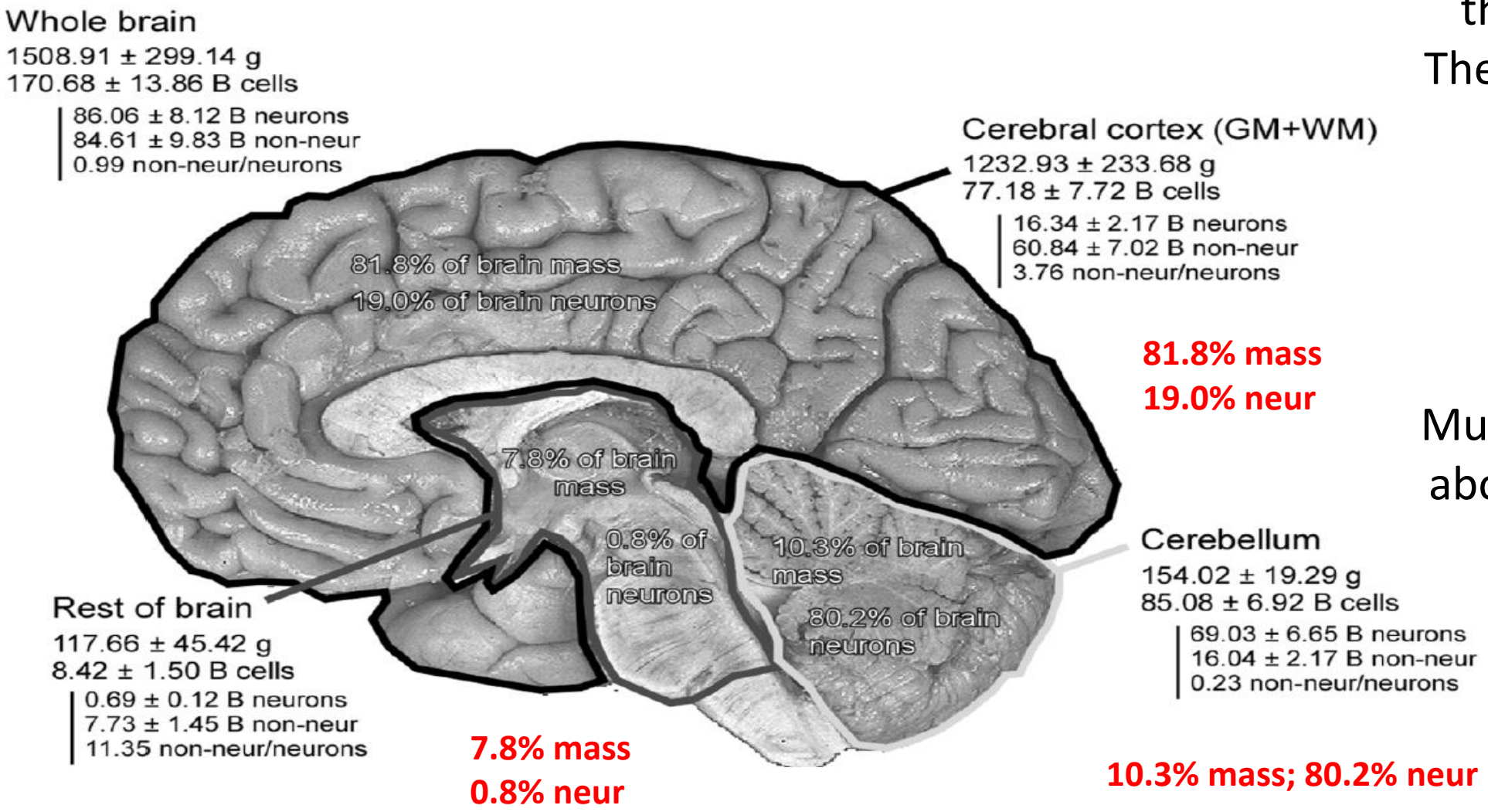
"... If we assume that a neuron can have a "clock frequency" of no better than roughly 10^2 Hz, then the clock frequencies of almost 1,000 MHz (that is, 10^9 basic operations per second) now displayed in the most recent generation of desktop machines push the neuron's disadvantage closer to a factor of 10^7. ... If the brain is a digital computer with a von Neumann architecture, it is doomed to be a computational tortoise by comparison. ... Conjointly, these two severe limitations – one on speed, and the other on accuracy – drive von Neumann to the conclusion that whatever computational regime the brain is using, it must be one that somehow involves a minimum of what he calls "logical depth". That is, whatever the brain is doing, it cannot be sequentially performing thousands upon thousands of sequentially computational steps."

Churchland, Paul & Patricia. 2000.

"... Given the slowness of its neuronal activities, there isn't enough time for the brain to complete any but the most trivial of computations. And given the low accuracy of its typical representations, it would be computationally incompetent even if it did have enough time.

... As we now know, the brain contains roughly 10^{14} synaptic connections, each of which modulates the arriving axonal signal before passing it on to the receiving neuron. ... Most important, **these tiny modulatory actions all take place simultaneously**. This means that, with each synapse being active perhaps 100 times per second ... the total number of basic information-processing actions performed by the brain must be roughly **10^2 times 10^{14}, or 10^{16} operations per second**. This is a striking achievement for any system, and it compares very favorably with our earlier count on 10^9 basic operations per second for a cutting edge desktop machine. The brain is neither a tortoise nor a dunce after all, for it was never a serial digital machine to begin with: **it is a massively parallel analog machine**."

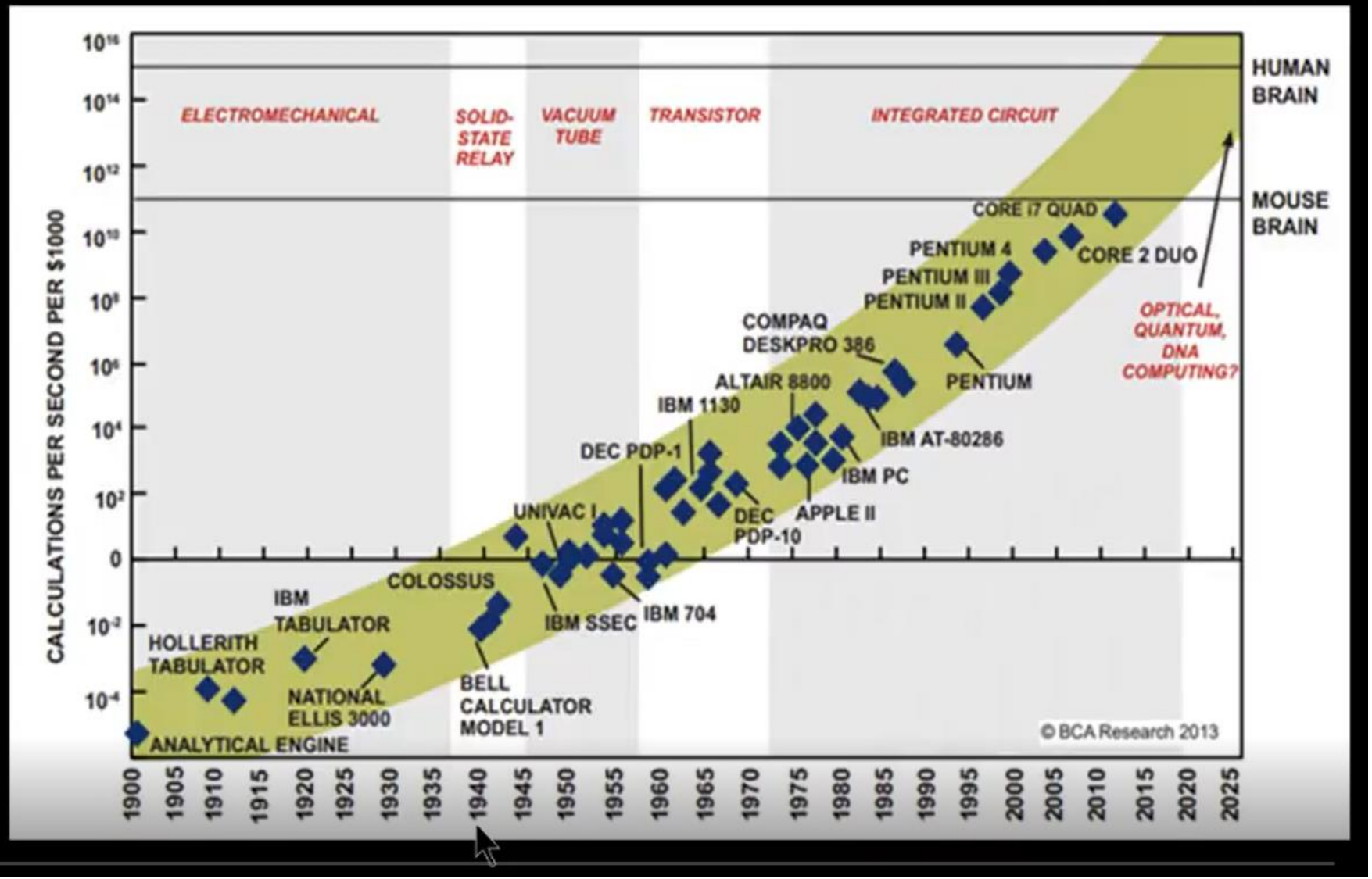
Azevedo, F. et al. 2009. Equal numbers of neuronal and nonneuronal cells make the human brain an isometrically scaled-up primate brain. *Journal of Comparative Neurology* 513.532-41.



Only half of the cells in the brain are neurons. The cerebellum, not the cortex, has most of these neurons. Researchers are now working on typing these neurons. Much less is understood about the non-neurons, though their importance for the functioning of the brain is self-evident.

Moore's Law

Number of elements on integrated circuits doubled every 1-2 years



The power of the **computer** increased steadily as its constituent units changed in structure & size. Successive miniaturization of the units allowed packing innumerable units into the IC board.

The **brain**, on the other hand, has no such recourse. The neurons are at their most numerous during youth. Failure to replace dysfunctional neurons inevitably result in **cognitive decline**.

Can a computer learn?

"A computer program is said to learn from experience *E* with respect to some class of tasks *T* and performance measure *P* if its performance at tasks in *T*, as measured by *P*, improves with experience *E.”* *T.M.Mitchell. 1997.*

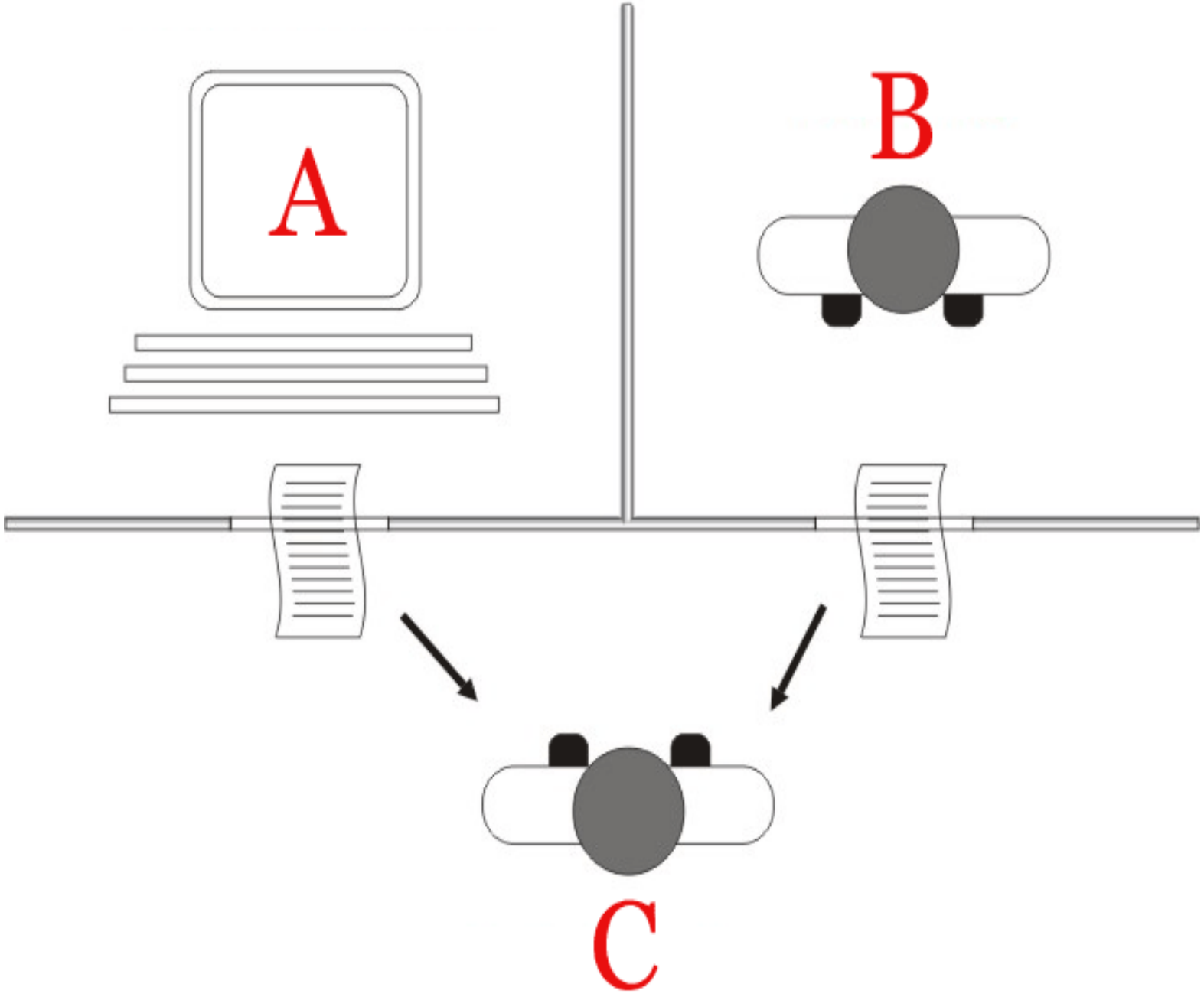
Hebbian learning:

"... When an axon of cell *A* is near enough to excite a cell *B* and repeatedly or persistently takes part in firing it, some growth process or metabolic change takes place in one or both cells such that *A*'s efficiency, as one of the cells firing *B*, is increased."

Hebb, D. O. 1949. The organization of behaviour. Wiley & Sons.

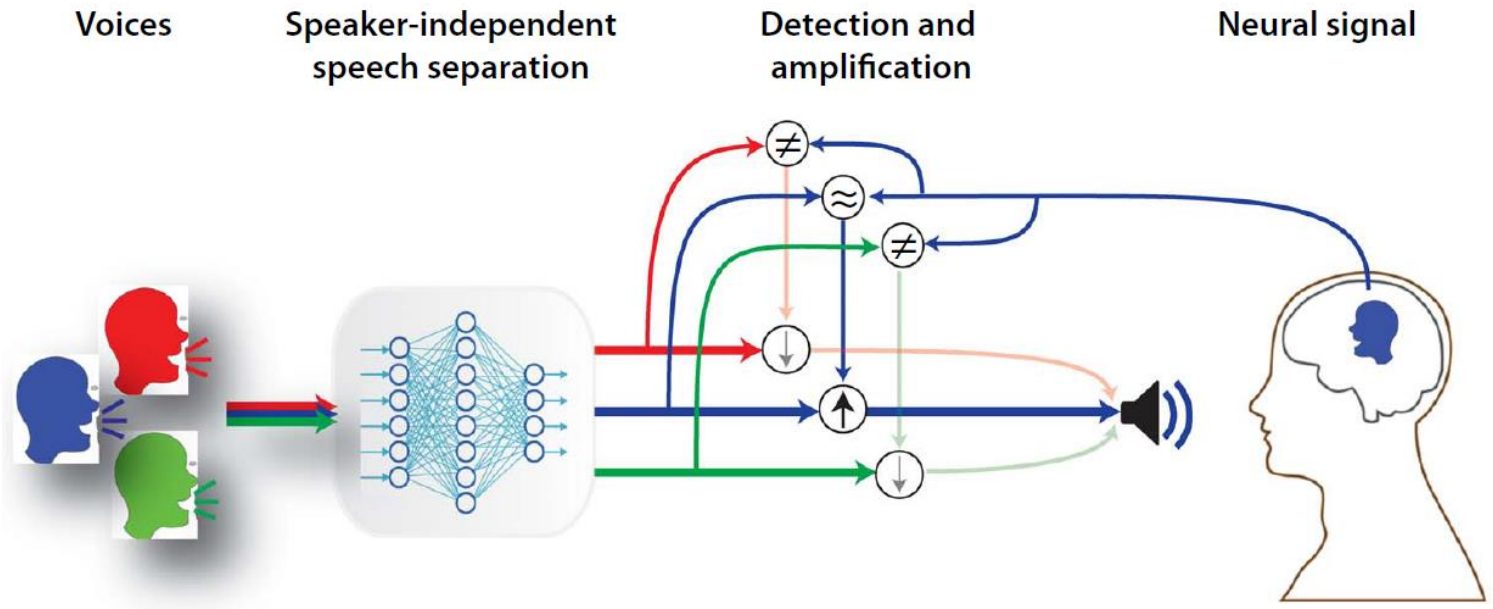
"neurons wire together if they fire together"

Löwel, S. & Singer, W. 1992. *Selection of Intrinsic Horizontal Connections in the Visual Cortex by Correlated Neuronal Activity.* *Science* 255:209-12."

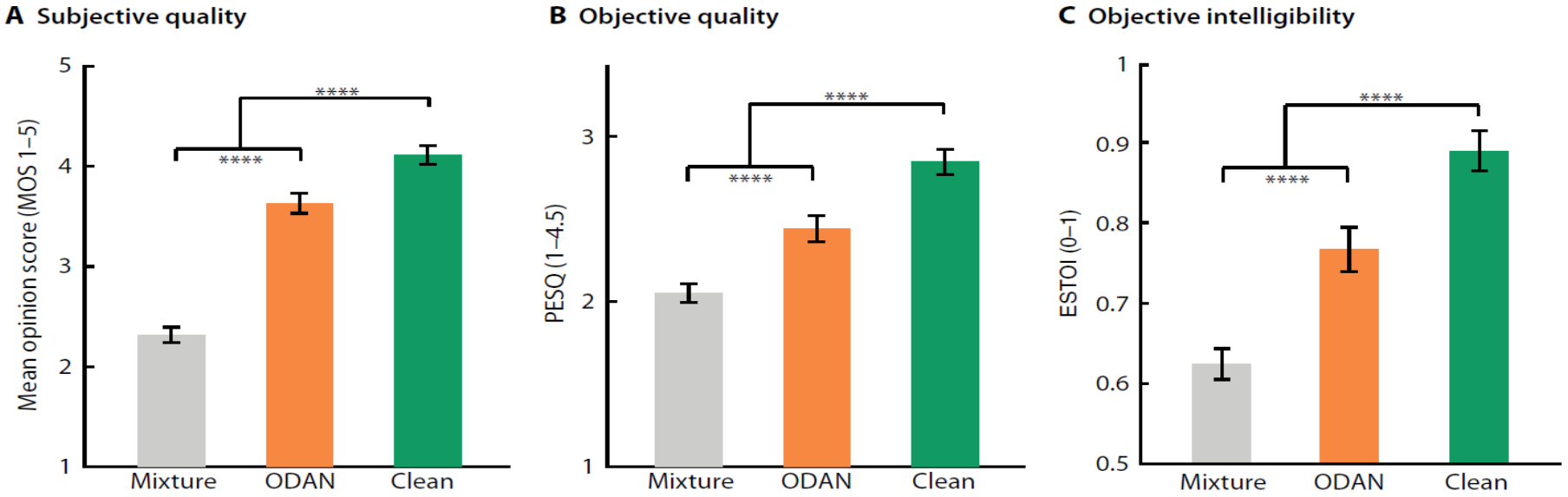


Turing, A. M. (1950). "Computing machinery and intelligence." *Mind* **59** : 433-460.

Searle, J. R. (2002). Twenty-one years in the Chinese room. Views into the Chinese Room. Clarendon Press.



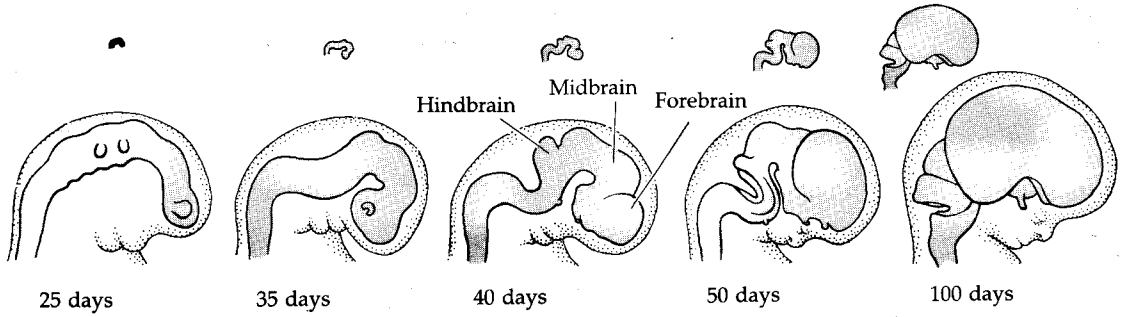
Cocktail Party Problem & its solution using Online Deep Attractor Network with Auditory Attention Decoding – **ODAN-AAD**. 3 patients (epilepsy) with subdural implants.

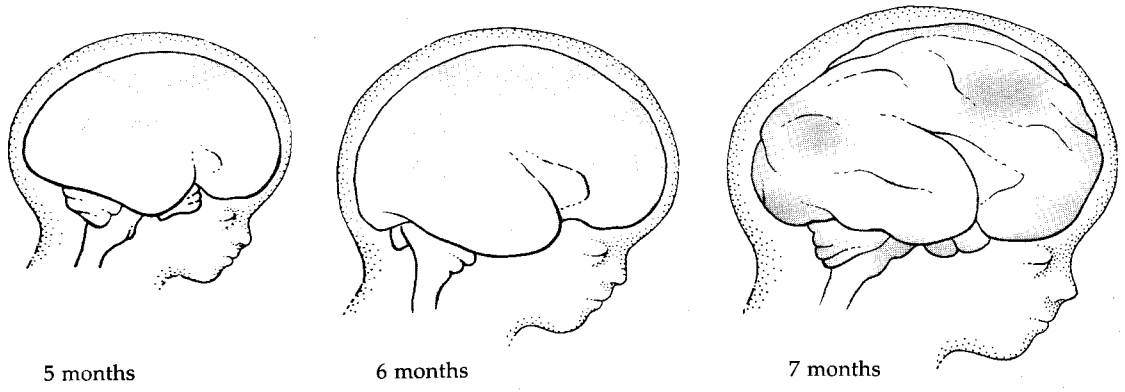


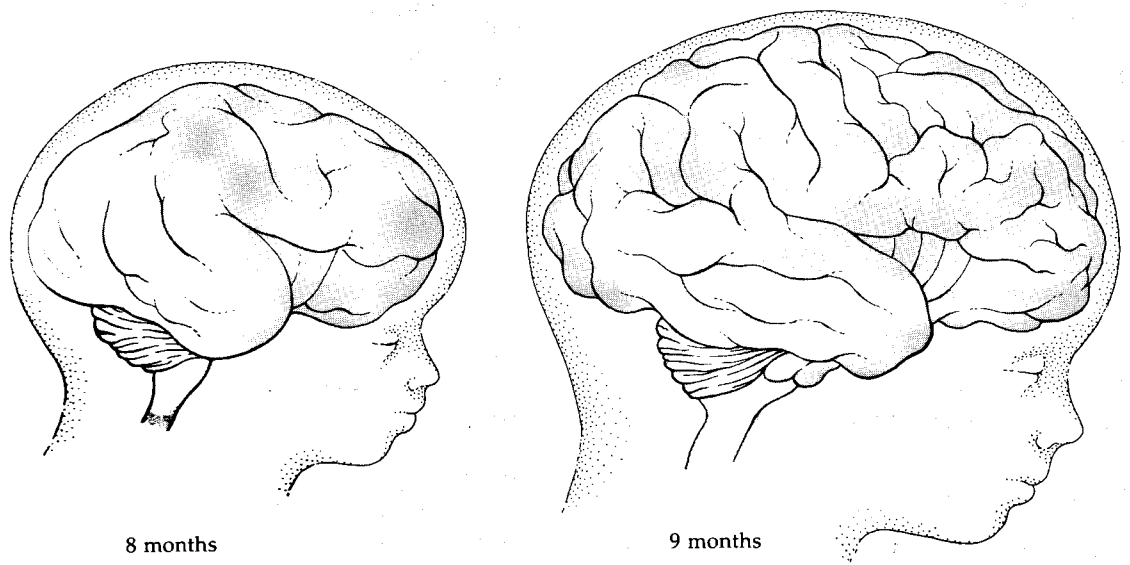
Han, C., et al. 2019. Speaker-independent auditory attention decoding without access to clean speech sources. *Sci Adv* **5**: eaav6134.

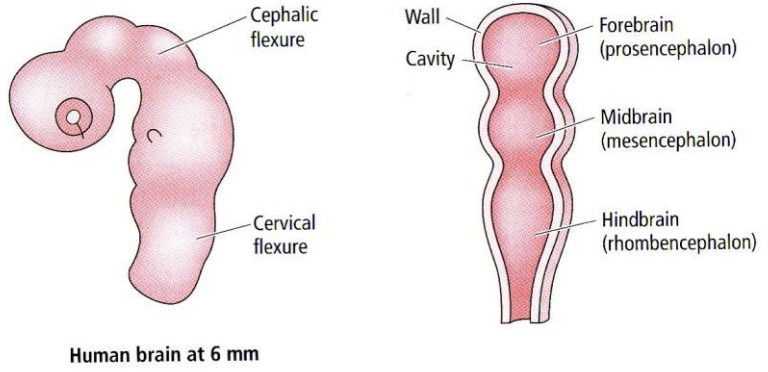
"… the AlphaGo Zero program recently achieved superhuman performance in the game of Go by reinforcement learning from self-play. In this paper, we generalize this approach into a **single AlphaZero algorithm** that can achieve superhuman performance in many challenging games. Starting from random play and given no domain knowledge except the game rules, **AlphaZero convincingly defeated a world champion program in the games of chess and shogi (Japanese chess), as well as Go**."

*Silver, D., et al. 2018. "A general reinforcement learning algorithm that masters chess, shogi, & Go through self-play." Science **362**: 1140-1144.*

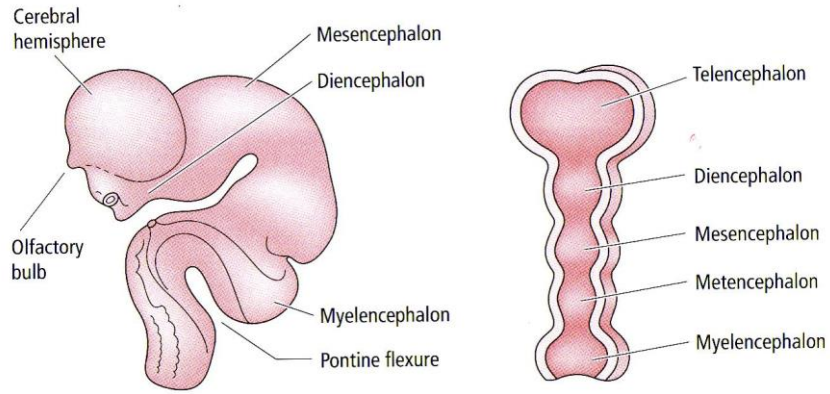








Human brain at 6 mm



Human brain at 27 mm

Purves, Dale, & Lichtman, Jeff W. 1985: 18. Figure 11.

Principles of Cognitive Neuroscience.

“Four orofacial gestures of a fetus at approximately 28 weeks GA.

(Top left) Grimacing;
(Top right) Finger sucking;
(Bottom left) TP to the side;
(Bottom right) tongue thrust. ”

Keven, N. & K.Akins. 2016.

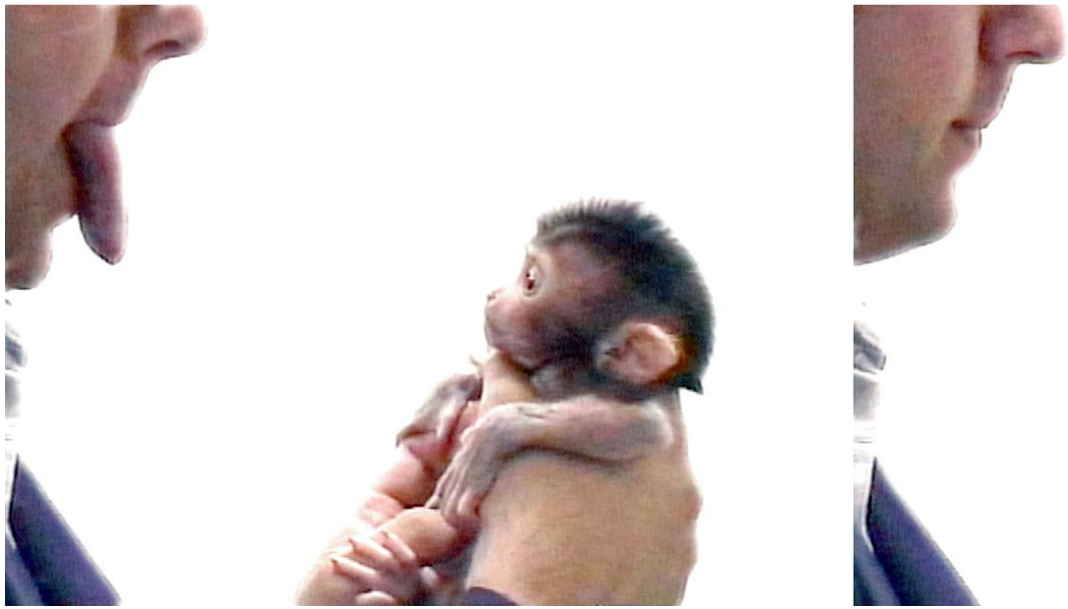
Neonatal Imitation in Context: Sensory-Motor Development in the Perinatal Period.

Behavioral and Brain Sciences Fig.2.

Imitation by primates & mirror neurons.

Arbib, M. A. 2013. How the Brain got Language: the Mirror System Hypothesis. *Oxford University Press.*

Gross, Liza. 2006.
Evolution of Neonatal Imitation.
PLoS Biology Vol. 4/9/2006, e311.



Meltzoff, A.N. & Moore, M.K. 1977.
Imitation of facial & manual gestures by human neonates.
Science 198, 75–78.

Saffran, J.R., et al. 1996. Statistical Learning by 8-Month-Old Infants. *Science* 274.1926-28.

tupirogolabubidakupadoti

padotibidakutupirotupiro

golabubidakupadotigolabu

bidakutupirogolabupadoti

Saffran, J.R., et al. 1996. Statistical Learning by 8-Month-Old Infants. *Science* 274.1926-28.

tupirogolabubidakupadoti

padotibidakutupirotupiro

golabubidakupadotigolabu

bidakutupirogolabupadoti

Kuhl, P. K., et al. 2008.
Phonetic learning as a pathway to language. Phil. Trans. R. Soc. B 363.979–1000.

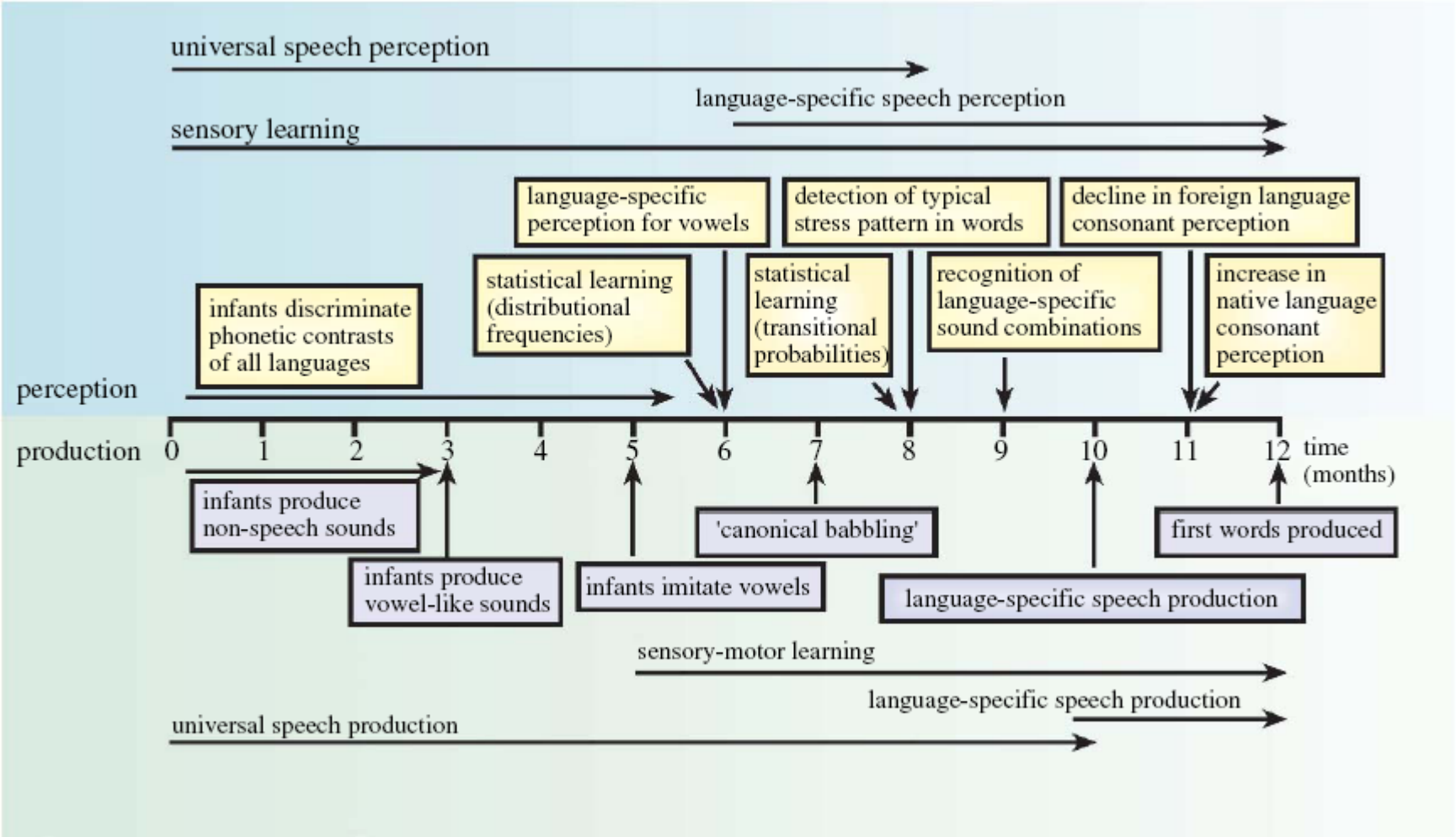
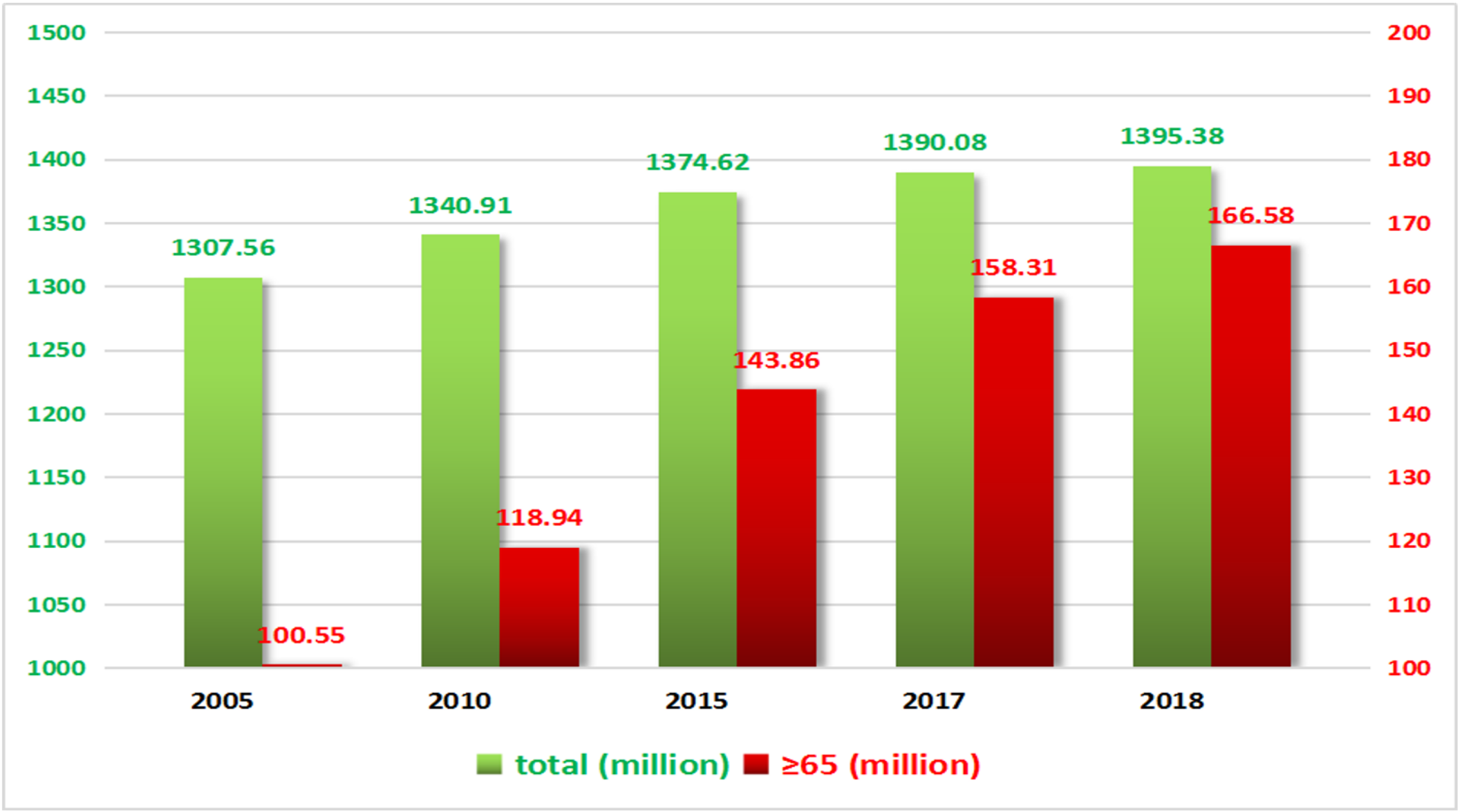


Figure 1. Universal timeline of infants' perception and production of speech in the first year of life. Modified from Kuhl (2004).

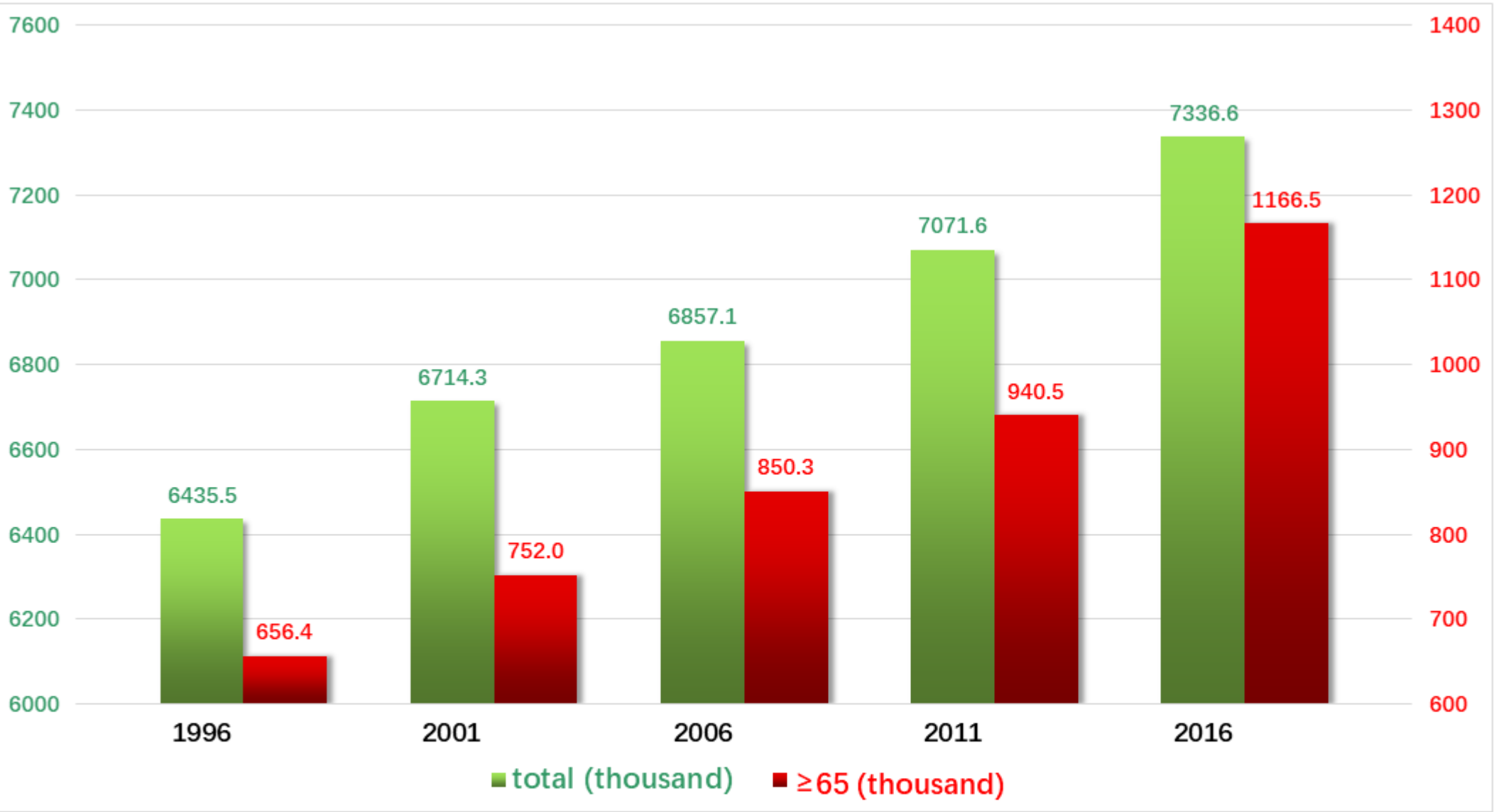


POPULATION AGEING in CHINA

GREEN: Total population in millions.

RED: Elders ≥ 65 population in millions.

In 2005, elders ≥ 65 were **8%** of the total population; in 2018 they have risen to **12%**.
Over this period, the total population has risen by **7%**; the elders have risen by **66%**.
Government survey: http://data.stats.gov.cn/easyquery.htm?cn=C01&zb=A0305&sj=2017.

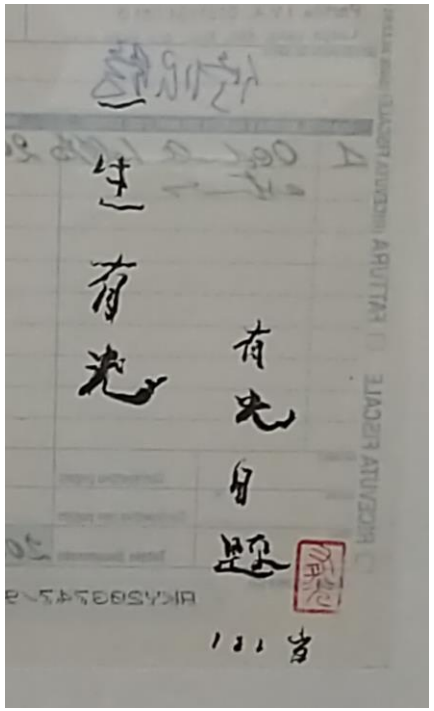


POPULATION AGEING in HONGKONG

GREEN: Total population in thousands.

RED: Elders ≥ 65 population in thousands.

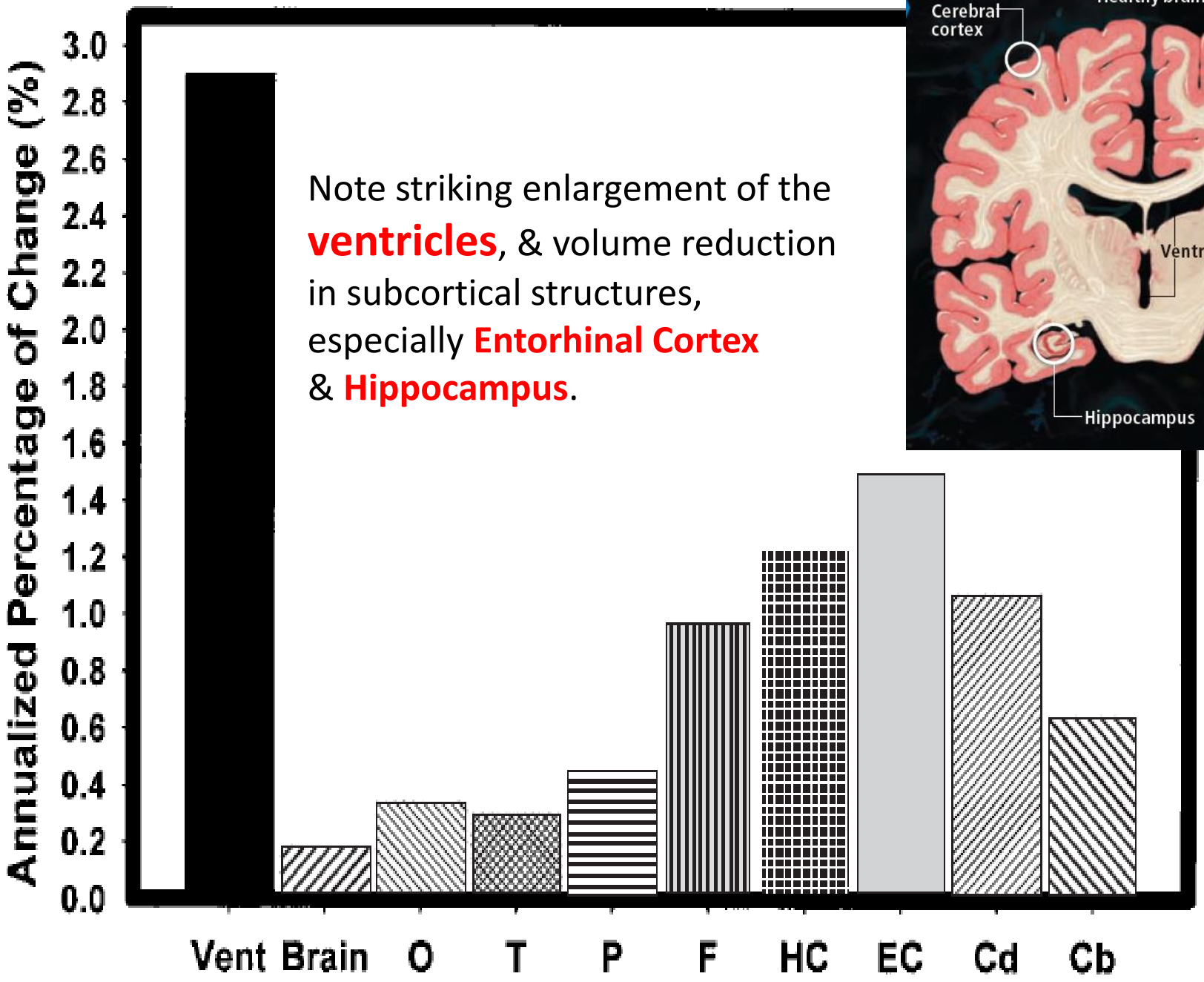
In 1996, elders ≥65 were **10%** of the total population; in 2016 they have risen to **16%**.
Over this period, the total population has risen by **14%**; the elder has risen by **78%**.
Government survey: https://www.censtatd.gov.hk/hkstat/sub/sp150_tc.jsp?productCode=B1120017.



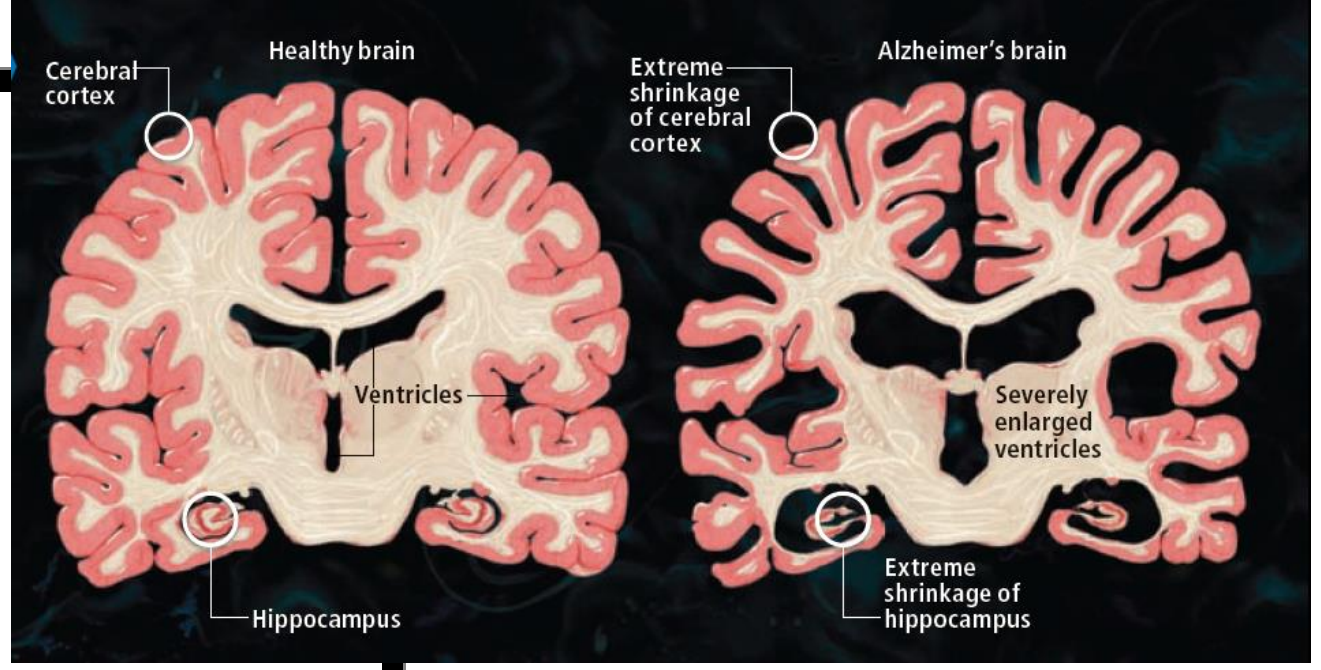
Zhou Youguang,
周有光,
1906 – 2017.
Advocate of
Hanyu Pinyin.

The longest human lifespan is that of **Jeanne Calment** of France (1875–1997), who lived to the age of 122 years, 164 days.

Professor Charles Kuen Kao (高錕) (1933-2018), was the recipient of a Nobel Prize in Physics in 2009, & was known as the
"Father of Fibre Optics".
He had Alzheimer's Disease, as did his father.

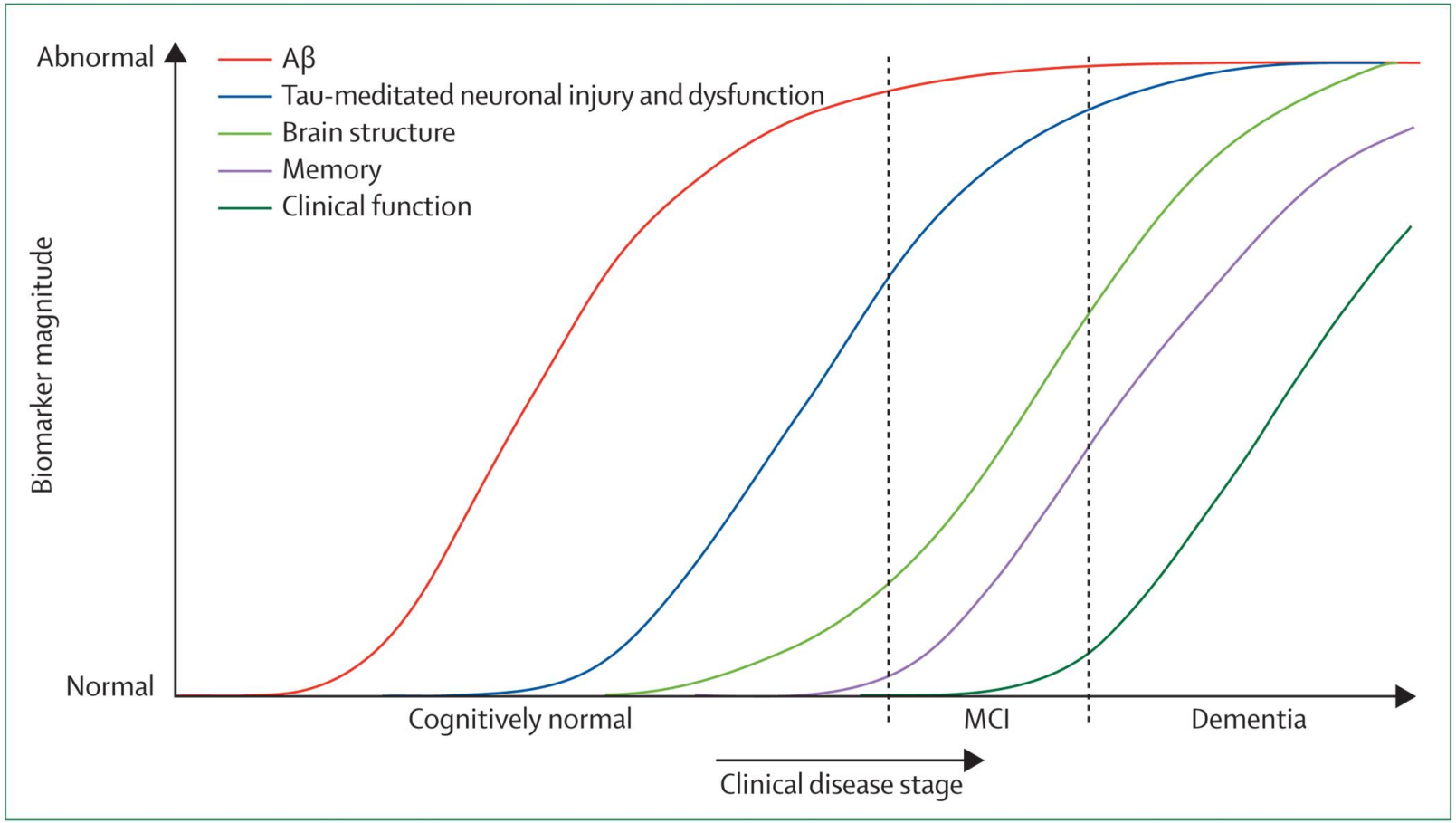


Note striking enlargement of the **ventricles**, & volume reduction in subcortical structures, especially **Entorhinal Cortex** & **Hippocampus**.



Cabeza, R.et al. eds. 2005:41. *Cognitive Neuroscience of Aging: Linking Cognitive and Cerebral Aging*: Oxford University Press.

Stix, G. 2010. Alzheimer's: Forestalling the darkness. *Scientific American* 50-7.



Jack, C.R., et al. (2010). Hypothetical model of dynamic biomarkers of the Alzheimer's pathological cascade. *Lancet Neurol. 9*(1), 119-128.

Tzeng, O. J. L. and W. S.-Y. Wang. 1983. The first two R's. American Scientist **71**: 238-243.

Stroop, J. R. 1935. Studies of interference in serial verbal reactions. Journal of Experimental Psychology **18**: 643-662.

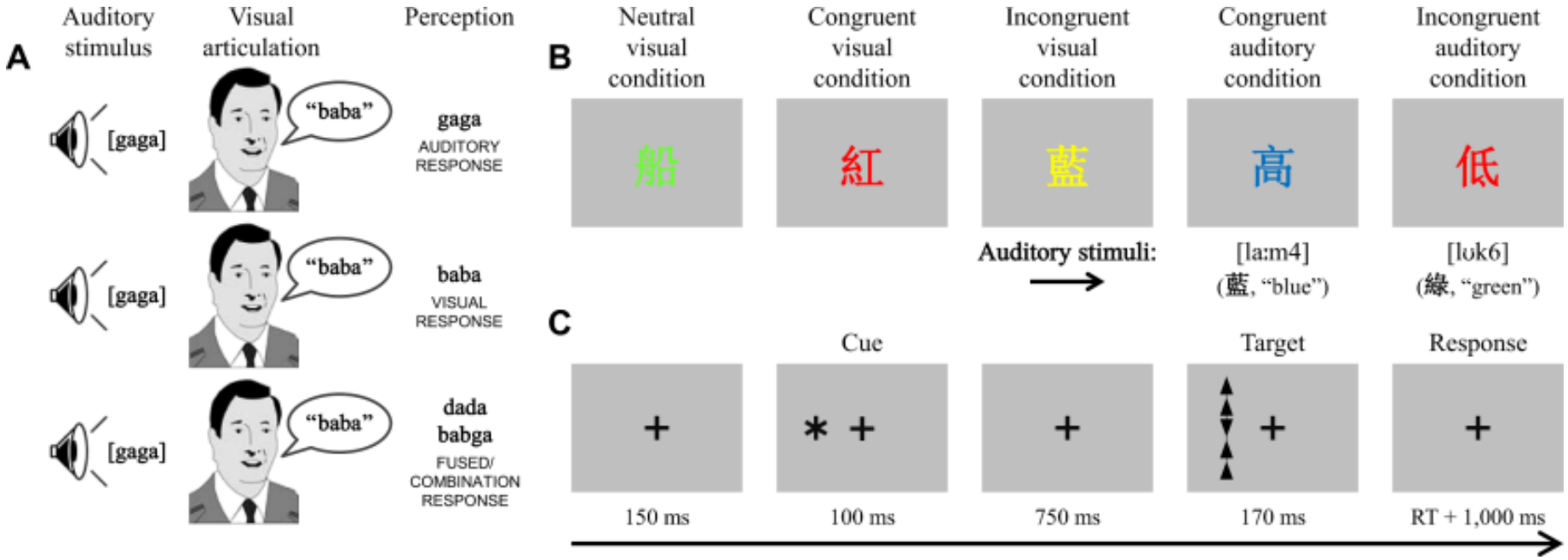
BLUE **PURPLE** **GREEN** **RED**

GREEN **BLUE** **RED** **PURPLE**

紅 紫 綠 藍

藍 綠 紅 紫

Multi-sensory Integration:
Stroop, McGurk, Eriksen Flanker Tasks



McGurk, H, & MacDonald, J (1976). *Nature* 264:746-8.
Stroop, JR (1935). *Journal of Experimental Psychology* 18(6):643-62.
Eriksen, BA, & Eriksen, CW (1974). *Perception and Psychophysics* 16:143-9.

Cabeza, R. 2002. Hemispheric asymmetry reduction in older adults: the HAROLD model. *Psychology & Aging* 17:85-100.

Mehta, J. & Jerger, J. (2014). Variation in semantic priming across age groups: An AERP study. *International Journal of Audiology* 53:235-242.

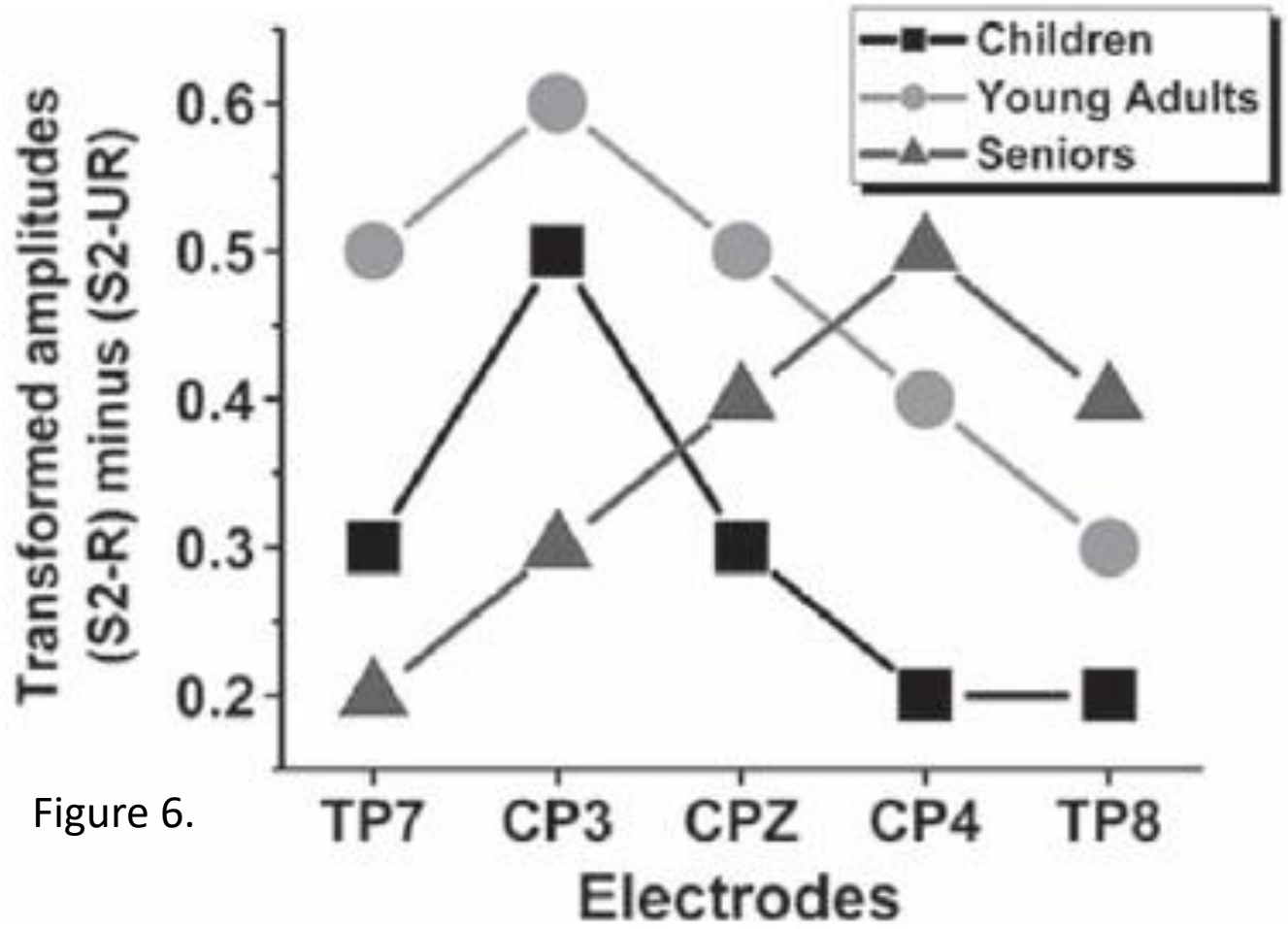


Figure 6.

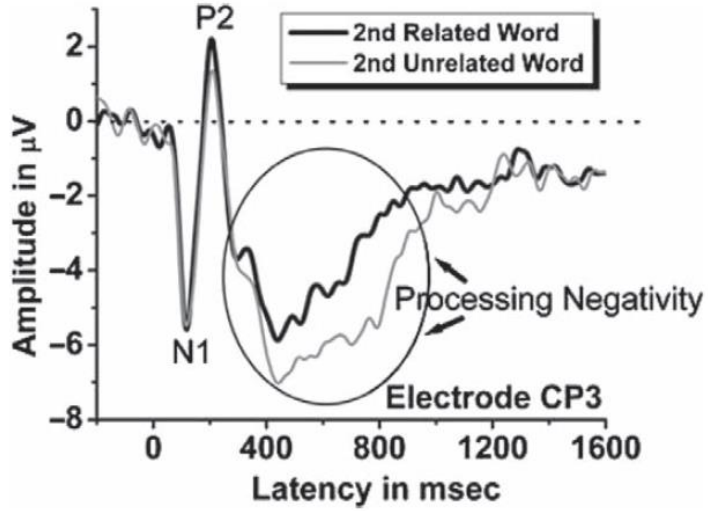


Figure 2.

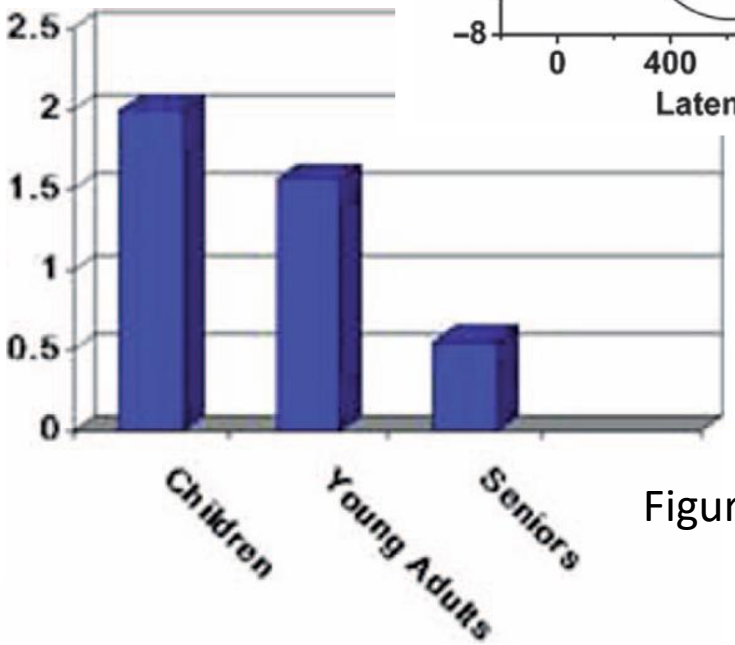


Figure 7.

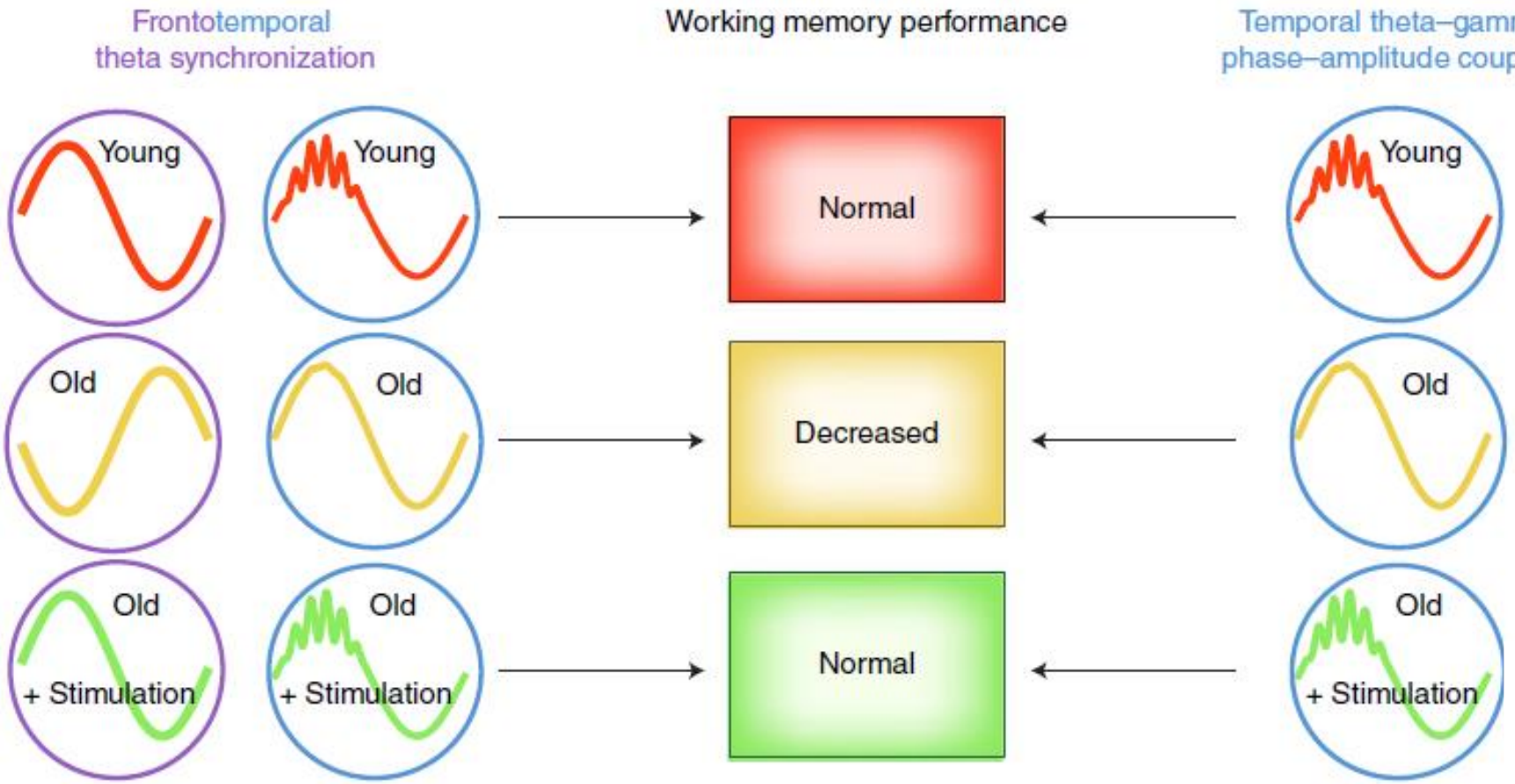
ARTICLES
https://doi.org/10.1038/s41593-019-0371-x
nature neuroscience

Working memory revived in older adults by synchronizing rhythmic brain circuits

Nature Neuroscience
22: 820-827, May 2019.

Robert M. G. Reinhart * and John A. Nguyen

Understanding normal brain aging and developing methods to maintain or improve cognition in older adults are major goals of fundamental and translational neuroscience. Here we show a core feature of cognitive decline—working-memory deficits—emerges from disconnected local and long-range circuits instantiated by theta–gamma phase–amplitude coupling in temporal cortex and theta phase synchronization across frontotemporal cortex. We developed a noninvasive stimulation procedure for modulating long-range theta interactions in adults aged 60–76 years. After 25 min of stimulation, frequency-tuned to individual brain network dynamics, we observed a preferential increase in neural synchronization patterns and the return of sender–receiver relationships of information flow within and between frontotemporal regions. The end result was rapid improvement in working-memory performance that outlasted a 50 min post-stimulation period. The results provide insight into the physiological foundations of age-related cognitive impairment and contribute to groundwork for future non-pharmacological interventions targeting aspects of cognitive decline.



Quentin, R. and L. G. Cohen (2019). Reversing working memory decline in the elderly. *Nature Neuroscience* **22**: 686-688.

"China already has a population of elderly of around 178 million (surpassing that of the number of elderly in all the European countries put together). It is estimated that by 2040 people aged 60 and older will make up about 28% of the population - in absolute numbers 397 million people … **Worries about the impact that the growing ranks of elderly will have on the economy and on individual families have been dubbed in China as the 4-2-1 problem because… a single person in China will soon be expected to support two parents and four grandparents.** The media are only now beginning to expose the ignorance and stigma long associated with dementia in China …"

Lock, M. 2013. The Alzheimer Conundrum: Entanglements of Dementia and Aging. Princeton University Press. p.16.

Vol 466|1 July 2010 nature

OPINION

Most people are not WEIRD

To understand human psychology, behavioural scientists must stop doing most of their experiments on Westerners, argue **Joseph Henrich**, **Steven J. Heine** and **Ara Norenzayan**.

"… Experimental findings from several disciplines indicate considerable variation among human populations in diverse domains, such as visual perception, analytic reasoning, fairness, cooperation, memory and the heritability of IQ. This is in line with what anthropologists have long suggested: that people from Western, educated, industrialized, rich and democratic (WEIRD) societies — and particularly American undergraduates — are some of the most psychologically unusual people on Earth. So the fact that the vast majority of studies use WEIRD participants presents a challenge to the understanding of human psychology and behaviour. A 2008 survey of the top psychology journals found that 96% of subjects were from Western industrialized countries — which house just 12% of the world's population. Strange, then, that research articles routinely assume that their results are broadly representative, rarely adding even a cautionary footnote on how far their findings can be generalized. … "

Cabeza, R. (2002). "Hemispheric asymmetry reduction in older adults: the HAROLD model." Psychology and Aging **17**(1): 85-100.
hemispheric-asymmetry reduction in older adults.

Davis, S. W., et al. (2008). "Que´ PASA? The Posterior--Anterior Shift in Aging." Cerebral Cortex **18**: 1201-1209. posterior–anterior shift in aging.

Reuter-Lorenz, P. A. and K. A. Cappell (2008). "Neurocognitive Aging & the Compensation Hypothesis." Psychological Science **17**(3): 177-182.
compensation-related utilization of neural circuits hypothesis. (CRUNCH)

It is crucial for us to know how much of current knowledge, derived primarily from WEIRD studies, is applicable to Chinese language and culture.

Poeppel, David and A.Marantz. 2000:33.
Cognitive Neuroscience of Speech Processing.

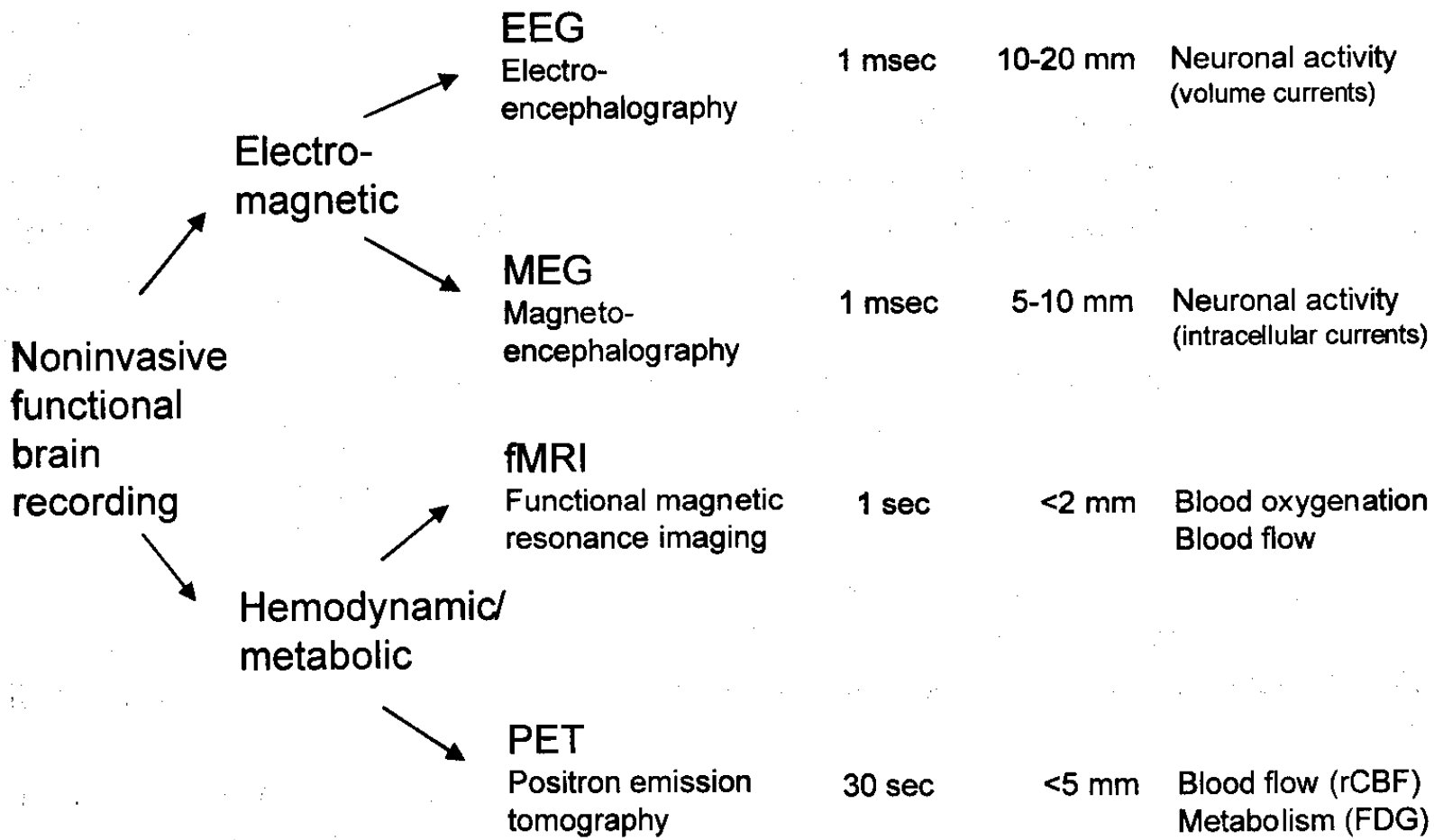
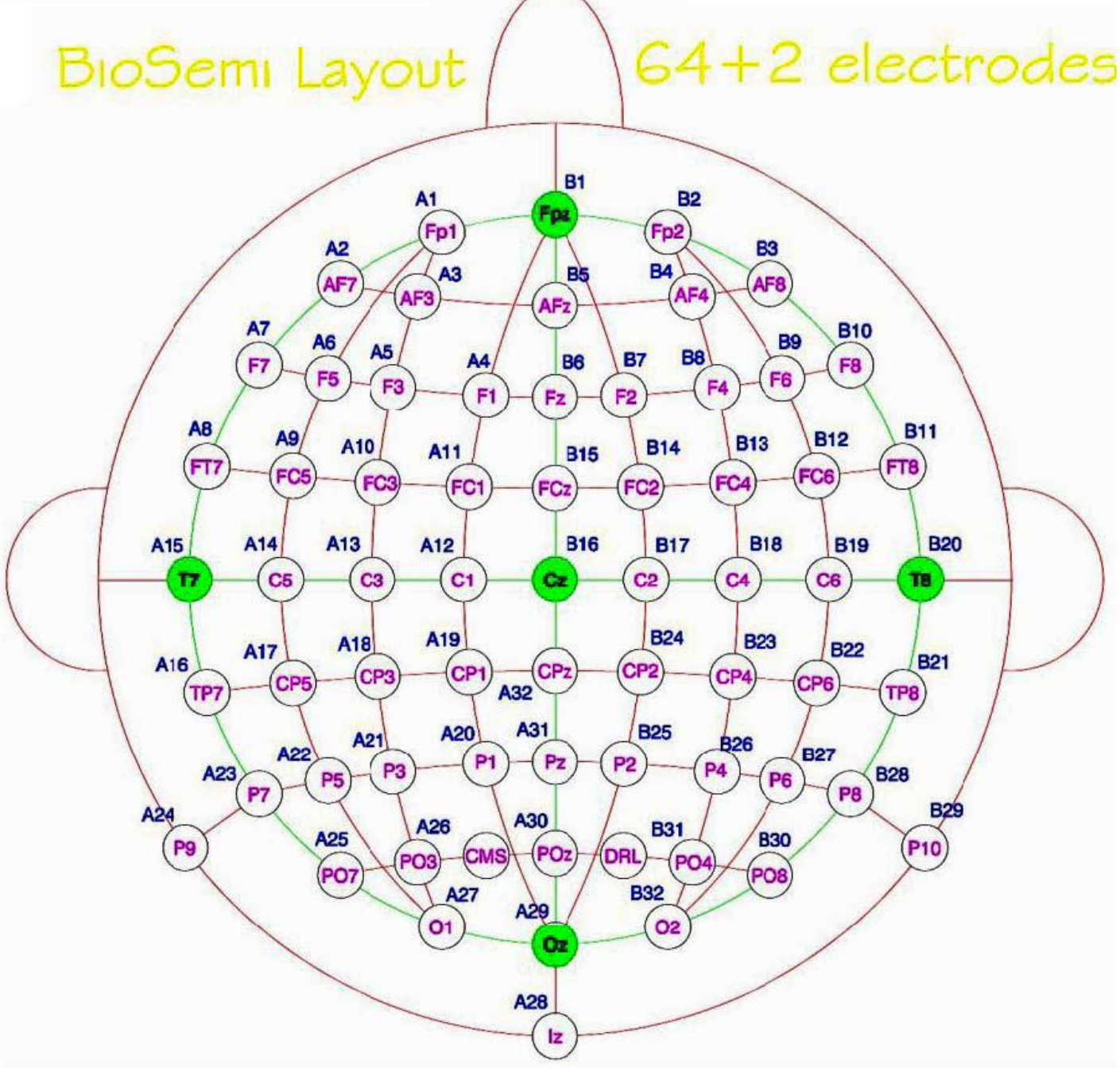
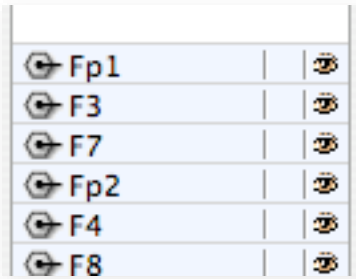


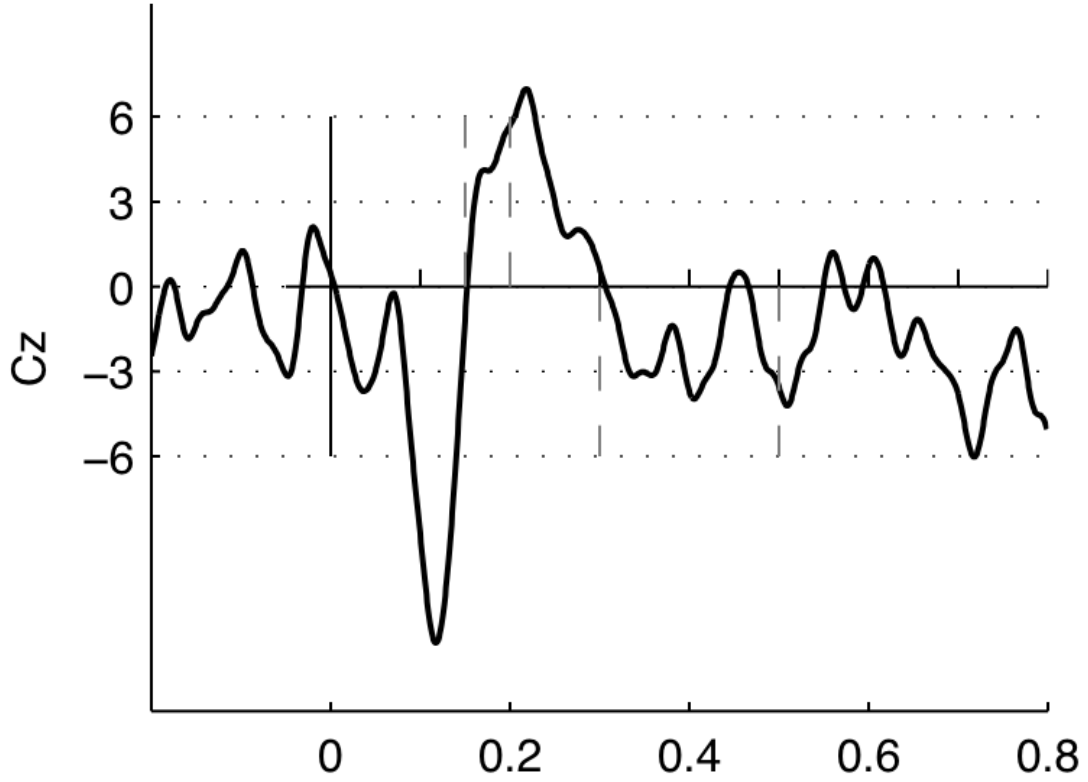
Figure 2.1
Summary of imaging methods.



Subject A. BioSemi 32 channel. 20160414 @ GH146 HKPU


Fp1
F3
F7
Fp2
F4
F8

Reducing intra-subject variations



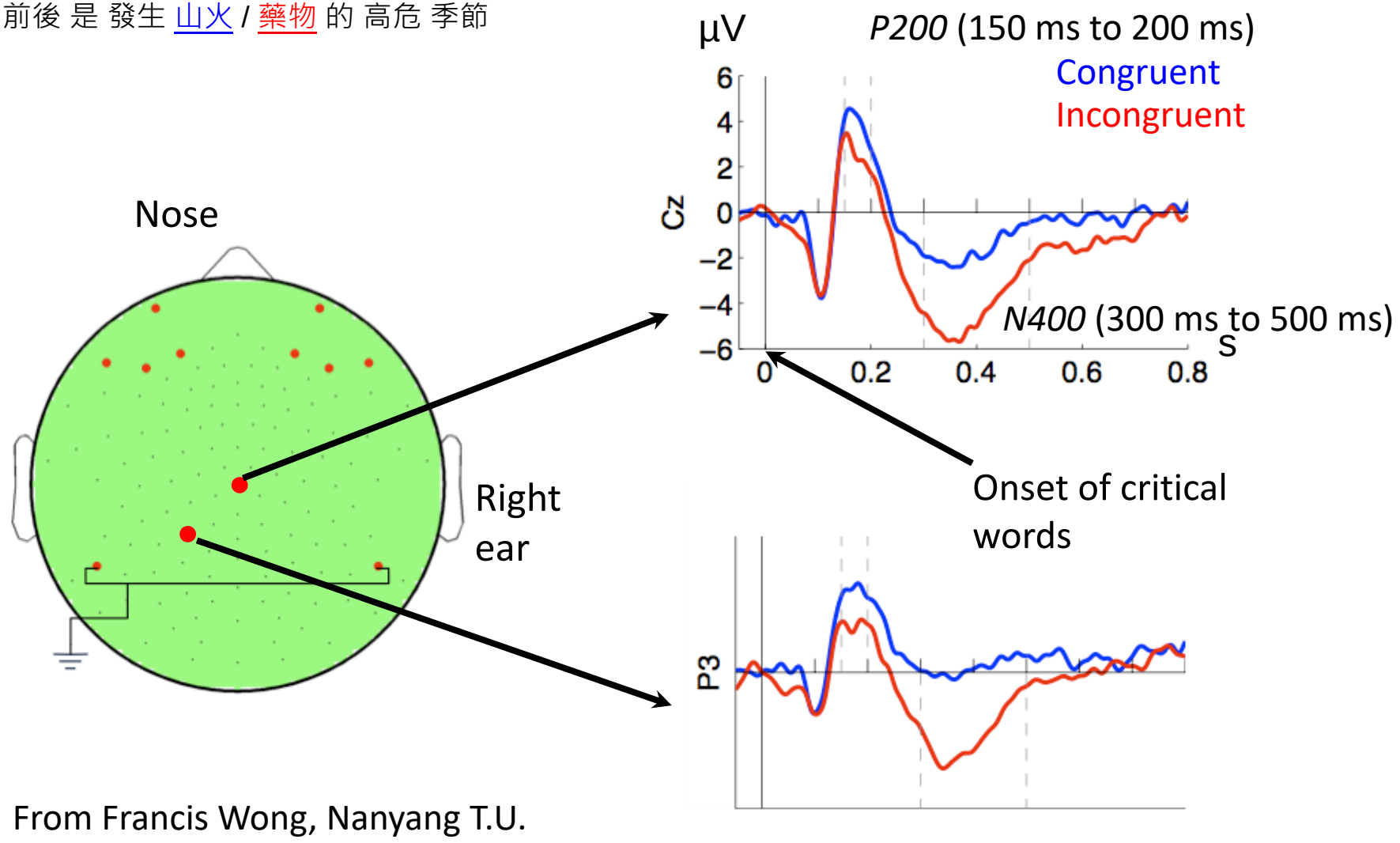
From EEG to single subject ERP:
Averaging over: 1, 2, 3, … 10, 15, 20, 25 trials

Congruent/Incongruent sentences in English:

The time of the year around Chung Yeung Festival is traditionally a high-risk period for hill fires / drugs

Congruent/Incongruent sentences in Chinese:

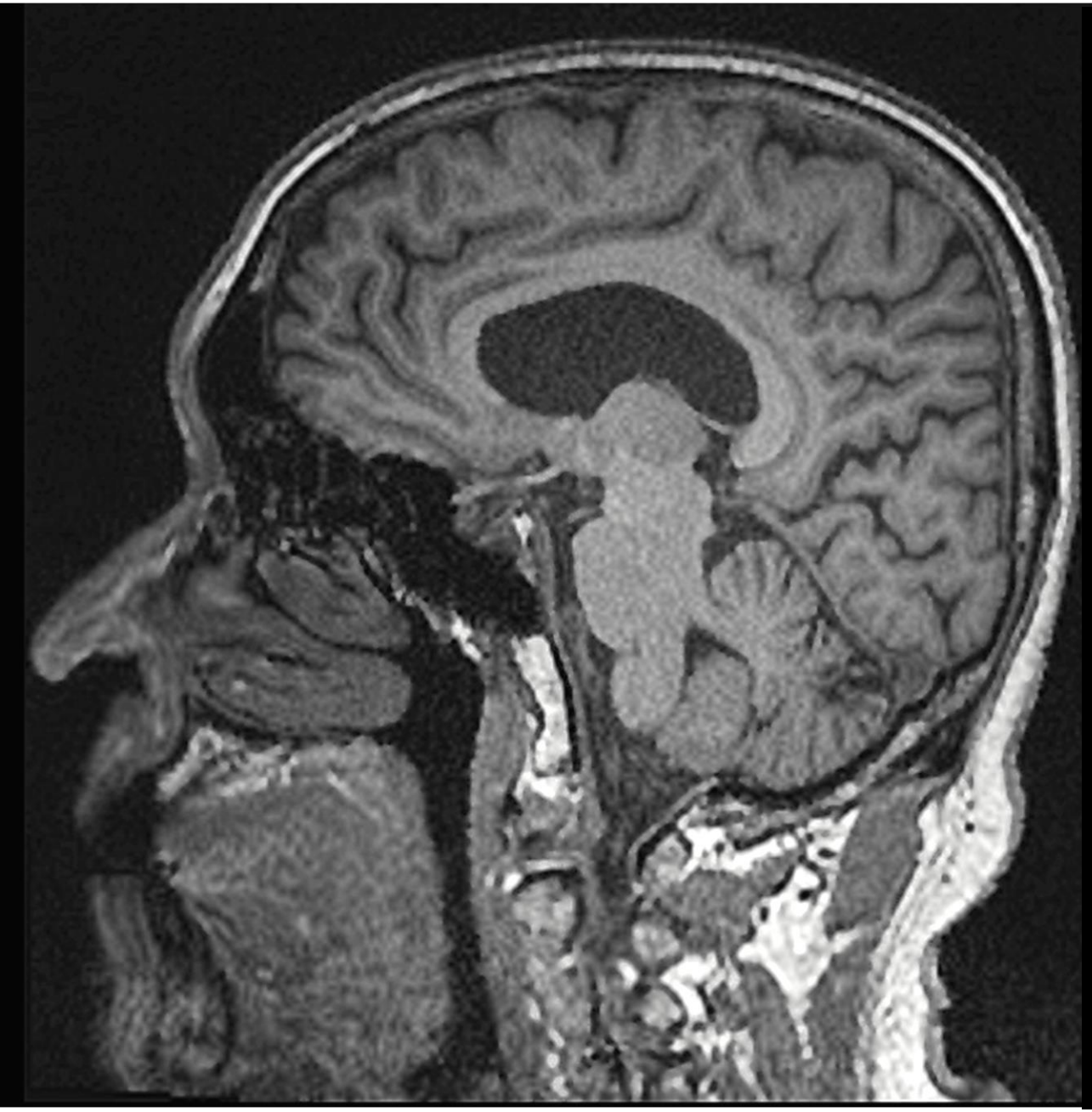
重陽節 前後 是 發生 山火 / 藥物 的 高危 季節



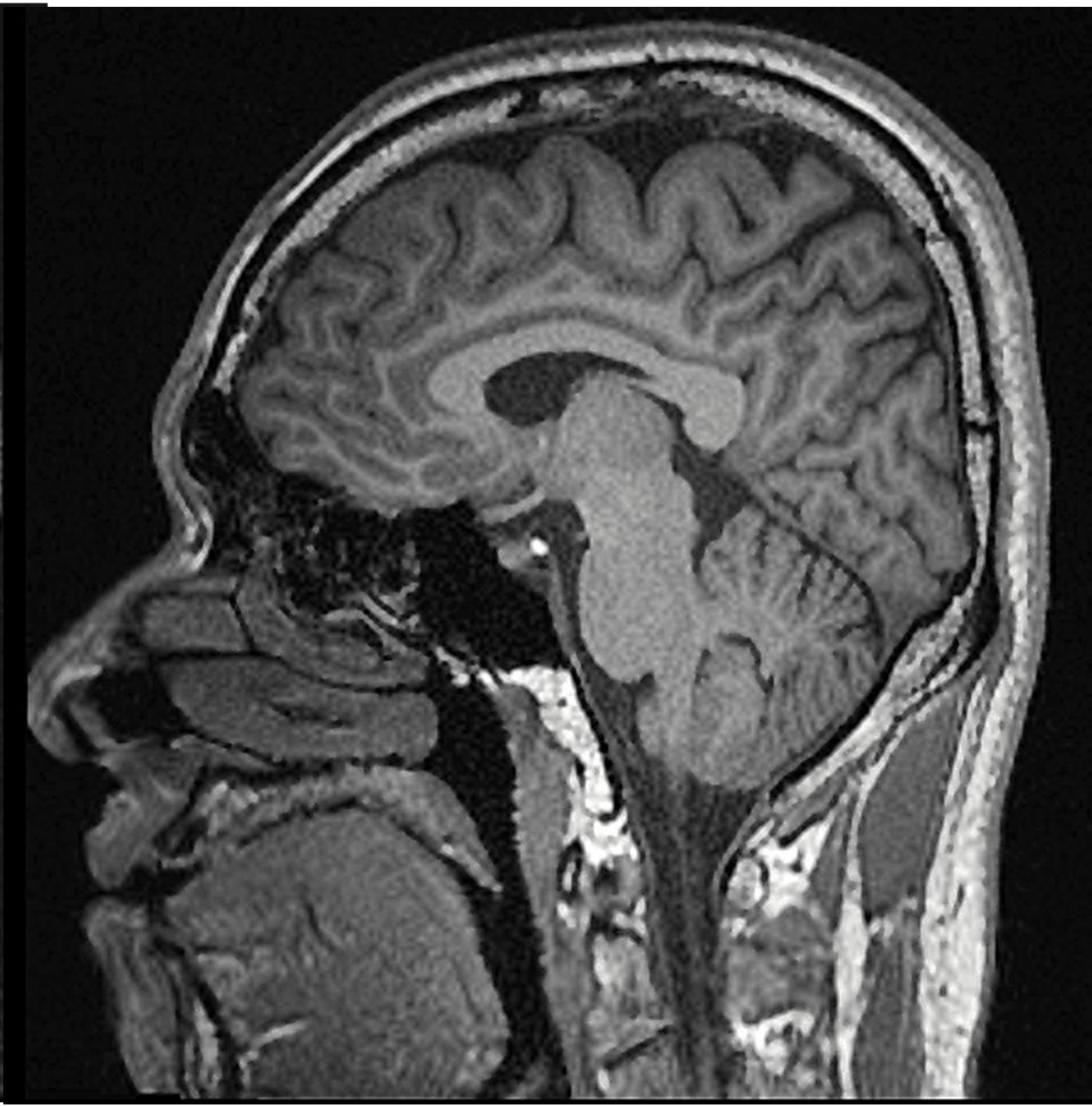
From Francis Wong, Nanyang T.U.

Subject: WSYW.
2017.10.10.
@ S.I.A.T.
Experimenter:
MCMF.

LEFT VENTRICLE: Frame number = 87 35,254 c.m.



Frame number = 91 5,256 c.m.



LANGUAGE, BRAIN & COMPUTER.

Language emerged around 100,000 years ago, when the human brain evolved to its present form. This combination of language and brain enabled our ancestors to collaborate, share information, and change the world in ways unique to our species. The computer was invented only about 100 years ago, causing the world to change at a new and explosive pace. I will draw from the three disciplines: linguistics, cognitive neuroscience, and COMPUTER science, to show how they influence each other. While obsolescent computers may be disassembled or discarded, the challenge is much more complex and severe in the case of elderly people with brains that have become dysfunctional. This is an urgent and immense problem our society is now facing, that we must all join forces to solve.

王士元. 2011.

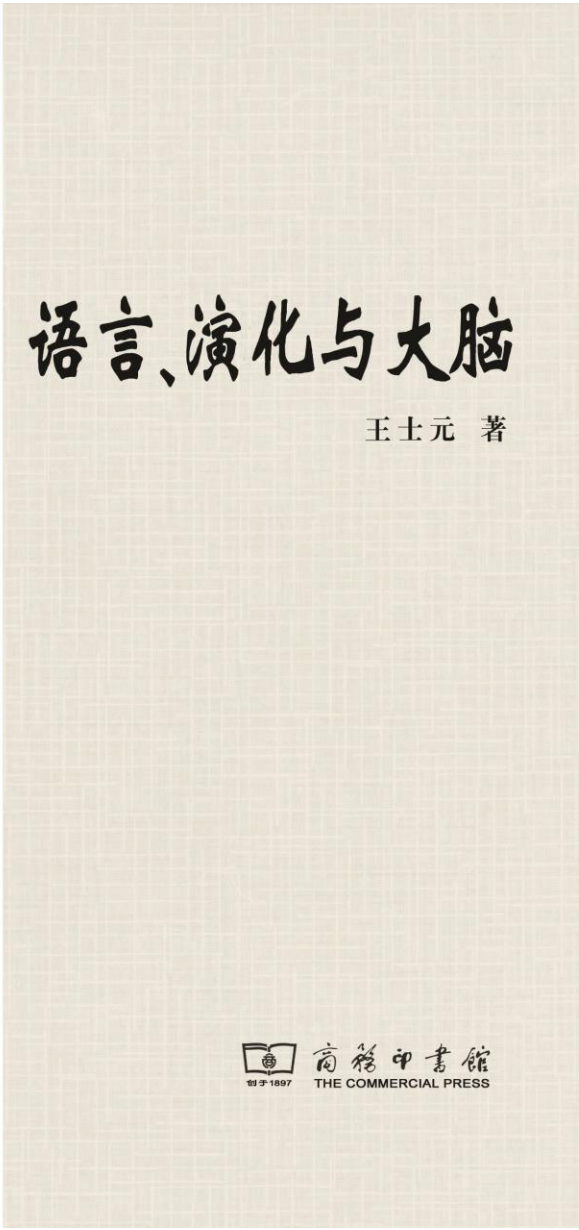
语言、演化与大脑.

北京, 商务印书馆.

---. 2014.

語言、演化與大腦.

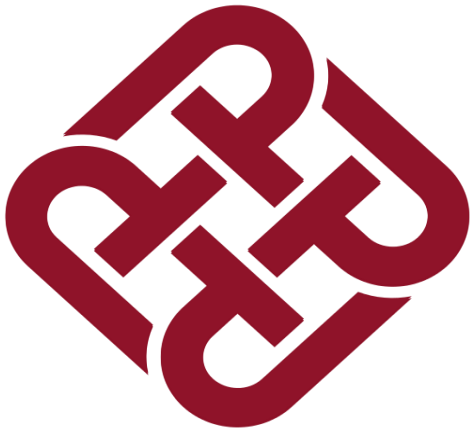
台北: 高等教育出版社.



Thank you!

謝謝！

3q!



For PDF file, email:

wsywang@polyu.edu.hk