

Available online at www.sciencedirect.com

ScienceDirect

Journal homepage: www.elsevier.com/locate/cortex

Special Issue "The Evolution of the Mind and the Brain": Editorial

Evolution of the mind and the brain

Michel Thiebaut de Schotten^{a,b,c,*} and Karl Zilles^d^a Brain Connectivity and Behaviour Laboratory, BCBlab, Sorbonne Universities, Paris, France^b Frontlab, Institut du Cerveau et de la Moelle épinière (ICM), UPMC UMRS 1127, Inserm U 1127, CNRS UMR 7225, Paris, France^c Groupe d'Imagerie Neurofonctionnelle, Institut des Maladies Neurodégénératives-UMR 5293, CNRS, CEA University of Bordeaux, Bordeaux, France^d Research Centre Juelich, Institute for Neuroscience and Medicine (INM-1), Juelich, Germany

ARTICLE INFO

Article history:

Received 29 May 2019

Accepted 3 June 2019

Published online xxx

If you could travel through time as if each second were a million years, primates would have appeared less than a minute ago, with only some walking on two legs less than 10 s ago (Jablonski & Chaplin, 1993), their first drawing some 500 ms ago (Mellet et al., 2018) and the carving of the first representation of a human face 250 ms ago (See Fig. 1). The relatively short span of our recorded history happened only in the last five milliseconds (Woods, 2010). What do we know about our origins? This question has captured the imagination of many scientists and writers for centuries. What was the level of awareness in primates, like us, thousands of years ago? How about our ancestors millions of years ago? Nature has left many clues for us to discover. If harvested the proper way, it will allow us combine statistics and imagination to decipher the laws of evolution— phylogeny.

Almost two centuries of comparative biology (Avisé, 2006), palaeontology (Mantell, 1822) and decades of phylogenetic inference (Miyamoto & Cracraft, 1991) has put forth scientific evidence to show that we are the fruit of billions of years of evolution. Evolution, as we understand it today, results from the balance of variability within a species and natural selection (Darwin, 1859). Every species strives for survival and

reproduction—the fittest succeed and the next generation inherit some of their phenotypes.

Similarities between species can be interpreted as preserved features, inherited from a common ancestor, whereas differences should emerge from more recent and novel configurations tested by natural selection. This hierarchy defines the evolutionary tree. While tremendous progress has been made in genetical model evolution, the phylogeny of the mind (i.e., cognition) and the brain (i.e., anatomy) remains poorly explored and understood.

Recent advances in behavioural and neuroimaging measures allow for the statistical exploration of new cognitive and anatomical dimensions in much larger cohorts than before. These technological advances have allowed us to re-evaluate and refute previously held theories, establish new rules of brain evolution, and assess how different from other species we actually are, to uncover what is remarkably unique to humans.

Surprisingly, the following articles demonstrate that non-human primates, when observed in their natural environment, behave more similarly to humans than previously thought (i.e., handedness in baboons, see Margiotoudi et al., 2019; communication, cooperation, trade and social learning in vervet monkeys, see Mertz, Surreault, van de Waal, & Botting, 2019), like our common ancestors, 30 million years ago, probably did. Some chimpanzees even recognise themselves in the mirror (Hopkins, Latzman, Mahovetz, Li, & Roberts, 2019) which puts forth questions relative to the level of self-awareness in non-human primates. Accordingly, it also suggests that the brain features that support self-awareness may have emerged about 6 million years ago.

* Corresponding author. Brain Connectivity and Behaviour Laboratory, BCBlab, Sorbonne Universities, Paris, France.

E-mail address: michel.thiebaut@gmail.com (M. Thiebaut de Schotten).

<https://doi.org/10.1016/j.cortex.2019.06.002>

0010-9452/© 2019 Elsevier Ltd. All rights reserved.



Fig. 1 – The Venus of Brassempouy is 25,000 years old and considered one of the earliest known realistic representations of a human face. © MAN/Loïc Hamon.

Whether these behaviours are learned or innate, they have a link to our phylogenetic past. The observation of new-borns can shed light onto innate behaviour. For instance, children are more likely to cradle objects with faces on the left side of their body (Forrester, Davis, Mareschal, Malatesta, & Todd, 2018). This left bias is pervasive among many species, which suggest that it is a very ancient evolutionary trait perhaps related to the right hemispheric dominance for emotions (Borod, Kent, Koff, Martin, & Alpert, 1988; Ioannucci, George, Cerliani, & Thiebaut de Schotten, 2017; Vallortigara & Rogers, 2005). Other functions, such as the discrimination of colours, show a shared contribution of innate perception and acquired knowledge that remains to be disentangled in order to understand its phylogeny (Siuda-Krzywicka, Boros, Bartolomeo, & Witzel, 2019).

Finally, learning advanced new skills is either supported by “neural reuse” mechanisms (e.g., reading and arithmetic Borra & Luppino, 2018; Dehaene & Cohen, 2007) or require new brain configurations (i.e., complex language) in primate evolution. These new brain configurations are generally understood to be unique to humans and are characterised by the fine-tuning of the microstructure (Palomero-Gallagher & Zilles, 2018) and connections of the brain (Eichert et al., 2018) through partially identified genetical mechanisms (Schreiweis et al., 2019).

This special issue of *Cortex* also includes manuscripts dedicated to an anatomical investigation of brain evolution. We will first discover that the expansion of exchanges between the cerebellum and the cortex (CCS) has a significant contribution to the size of the human brain (Smaers & Vanier, 2019). We will then confirm that phylogenetically closer primates species have a cortex mantle folded more similarly

than distant primates species (Heuer et al., 2019) and that folding can be partially explained by an imbalance between cortical expansion and subjacent white matter connections (Foubet, Trejo, & Toro, 2018). Fundamental differences in white matter also exist across primates, especially in language areas (Eichert et al., 2018). The emergence of language areas is not simple and required the displacement of extrastriate cortex posteriorly to leave room for the expansion of temporal association cortex and its connectivity (Bryant et al., 2019). These latter results suggest that models of evolutionary expansion are not yet accurate enough to account for highly non-linear changes. For example, some areas appeared during primate evolution (e.g., portions of TPJ see Patel, Sestieri, & Corbetta, 2019) and cannot be modelled using classical or advanced deformation algorithms (Klein et al., 2009) which are not built to generate new information. Further, evolution can split functional fields (e.g., the FEF, Petit & Pouget, 2019), swap brain regions (e.g., MT and MST, Patel et al., 2019), and produce territories that gather and integrate separate trends of expansion (i.e., the dual origin of the cerebral cortex, see Goulas, Margulies, Bezgin, & Hilgetag, 2019). Hence, additional work is required first to understand, and subsequently, model these evolutionary changes.

It is also important to acknowledge that other species have also evolved along with the human brain according to environmental constraints or preferences which have led to the emergence of unique features of their own (Herold et al., 2018; Staes et al., 2018). For instance, Louail et al. (Louail, Gilissen, Prat, Garcia, & Bouret, 2019) demonstrate that the scarcity of food resources has left an imprint onto the prefrontal cortex, as starvation and feeding favorize survival of individuals with the required cognitive skills (i.e., effective decision-making and episodic memory). The brain of non-human primates species is also as variable as the human brain (Croxson, Forkel, Cerliani, & Thiebaut de Schotten, 2017; Hopkins et al., 2019), and between species, comparisons should take into account this variability (Thiebaut de Schotten & Shallice, 2017) in order to avoid potential biases.

Hence, a wealth of questions remains, and further explorations are required in order to decipher phylogeny and build a precise evolutionary tree. The task is colossal and will require a joint communal effort to achieve a reliable and comprehensive result (Milham et al., 2018; Thiebaut de Schotten, Croxson, & Mars, 2018). At the dawn of open science, this special issue entitled “The evolution of the mind and the brain” is a demonstration that we can strengthen research and make a more significant contribution by linking our work together, rather than publishing our original contributions independently. Organising task-forces, sharing data and ideas will be critical to succeed in the endeavour of building a prosperous model of the evolution of mind and brain.

REFERENCES

- Avise, J. C. (2006). *Evolutionary pathways in nature: A phylogenetic approach*. Cambridge: Cambridge University Press.
- Borod, J. C., Kent, J., Koff, E., Martin, C., & Alpert, M. (1988). Facial asymmetry while posing positive and negative emotions:

- Support for the right hemisphere hypothesis. *Neuropsychologia*, 26(5), 759–764.
- Borra, E., & Luppino, G. (2018). Large-scale temporo-parietal-frontal networks for motor and cognitive motor functions in the primate brain. *Cortex*. <https://doi.org/10.1016/j.cortex.2018.09.024>.
- Bryant, K. L., Glasser, M. F., Li, L., Jae-Cheol Bae, J., Jacquez, N. J., Alarcon, L., et al. (2019). Organization of extrastriate and temporal cortex in chimpanzees compared to humans and macaques. *Cortex*. <https://doi.org/10.1016/j.cortex.2019.02.010>.
- Croxson, P. L., Forkel, S. J., Cerliani, L., & Thiebaut de Schotten, M. (2017). Structural variability across the primate brain: A cross-species comparison. *Cerebral Cortex*, 1–13. <https://doi.org/10.1093/cercor/bhx244>.
- Darwin, C. (1859). *On the origin of species by means of natural selection, or the preservation of favoured races in the struggle for life*. London: John Murray.
- Dehaene, S., & Cohen, L. (2007). Cultural recycling of cortical maps. *Neuron*, 56(2), 384–398. <https://doi.org/10.1016/j.neuron.2007.10.004>.
- Eichert, N., Verhagen, L., Folloni, D., Jbabdi, S., Khrapitchev, A. A., Sibson, N. R., et al. (2018). What is special about the human arcuate fasciculus? Lateralization, projections, and expansion. *Cortex*. <https://doi.org/10.1016/j.cortex.2018.05.005>.
- Forrester, G. S., Davis, R., Mareschal, D., Malatesta, G., & Todd, B. K. (2018). The left cradling bias: An evolutionary facilitator of social cognition? *Cortex*. <https://doi.org/10.1016/j.cortex.2018.05.011>.
- Foubet, O., Trejo, M., & Toro, R. (2018). Mechanical morphogenesis and the development of neocortical organisation. *Cortex*. <https://doi.org/10.1016/j.cortex.2018.03.005>.
- Goulas, A., Margulies, D. S., Bezgin, G., & Hilgetag, C. C. (2019). The architecture of mammalian cortical connectomes in light of the theory of the dual origin of the cerebral cortex. *Cortex*. <https://doi.org/10.1016/j.cortex.2019.03.002>.
- Herold, C., Schlomer, P., Mafoppa-Fomat, I., Mehlhorn, J., Amunts, K., & Axer, M. (2018). The hippocampus of birds in a view of evolutionary connectomics. *Cortex*. <https://doi.org/10.1016/j.cortex.2018.09.025>.
- Heuer, K., Gulban, O. F., Bazin, P. L., Osoianu, A., Valabregue, R., Santin, M., et al. (2019). Evolution of neocortical folding: A phylogenetic comparative analysis of MRI from 33 primate species. *Cortex*. <https://doi.org/10.1016/j.cortex.2019.04.011> (in press).
- Hopkins, W. D., Latzman, R. D., Mahovetz, L. M., Li, X., & Roberts, N. (2019). Investigating individual differences in chimpanzee mirror self-recognition and cortical thickness: A vertex-based and region-of-interest analysis. *Cortex*. <https://doi.org/10.1016/j.cortex.2019.05.004> (in press).
- Ioannucci, S., George, N., Cerliani, L., & Thiebaut de Schotten, M. (2017). White matter correlates of hemi-face dominance in emotional expression. *BioRxiv*. <https://doi.org/10.1101/232926> (in press).
- Jablonski, N. G., & Chaplin, G. (1993). Origin of habitual terrestrial bipedalism in the ancestor of the Hominidae. *Journal of Human Evolution*, 24, 259–280.
- Klein, A., Andersson, J., Ardekani, B. A., Ashburner, J., Avants, B., Chiang, M. C., et al. (2009). Evaluation of 14 nonlinear deformation algorithms applied to human brain MRI registration. *Neuroimage*, 46(3), 786–802. <https://doi.org/10.1016/j.neuroimage.2008.12.037>.
- Louail, M., Gilissen, E., Prat, S., Garcia, C., & Bouret, S. (2019). Refining the ecological brain: Strong relation between the ventromedial prefrontal cortex and feeding ecology in five primate species. *Cortex*. <https://doi.org/10.1016/j.cortex.2019.03.019>.
- Mantell, G. (1822). *The Fossils of the south downs: London* (Vol. 13). Cornhill: Lupton Relfe.
- Margiotoudi, K., Marie, D., Claidiere, N., Coulon, O., Roth, M., Nazarian, B., et al. (2019). Handedness in monkeys reflects hemispheric specialization within the central sulcus. An in vivo MRI study in right- and left-handed olive baboons. *Cortex*. <https://doi.org/10.1016/j.cortex.2019.01.001>.
- Mellet, E., Salagnon, M., Majki, A., Cremona, S., Joliot, M., Jobard, G., et al. (2018). *Neuroimaging supports the representational nature of the earliest human engravings*. *bioRxiv*.
- Mertz, J., Surreault, A., van de Waal, E., & Botting, J. (2019). Primates are living links to our past: The contribution of comparative studies with wild vervet monkeys to the field of social cognition. *Cortex*. <https://doi.org/10.1016/j.cortex.2019.03.007>.
- Milham, M. P., Ai, L., Koo, B., Xu, T., Amiez, C., Balezeau, F., et al. (2018). An open resource for non-human primate imaging. *Neuron*, 100(1), 61–74. <https://doi.org/10.1016/j.neuron.2018.08.039>. e62.
- Miyamoto, M. M., & Cracraft, J. (1991). *Phylogenetic analysis of DNA sequences*. New York: Oxford University Press.
- Palomero-Gallagher, N., & Zilles, K. (2018). Differences in cytoarchitecture of Broca's region between human, ape and macaque brains. *Cortex*. <https://doi.org/10.1016/j.cortex.2018.09.008>.
- Patel, G. H., Sestieri, C., & Corbetta, M. (2019). The evolution of the temporoparietal junction and posterior superior temporal sulcus. *Cortex*. <https://doi.org/10.1016/j.cortex.2019.01.026>.
- Petit, L., & Pouget, P. (2019). The comparative anatomy of frontal eye fields in primates. *Cortex*. <https://doi.org/10.1016/j.cortex.2019.02.023>.
- Schreiweis, C., Irinopoulou, T., Vieth, B., Laddada, L., Oury, F., Burguiere, E., et al. (2019). Mice carrying a humanized Foxp2 knock-in allele show region-specific shifts of striatal Foxp2 expression levels. *Cortex*. <https://doi.org/10.1016/j.cortex.2019.01.008>.
- Siuda-Krzywicka, K., Boros, M., Bartolomeo, P., & Witzel, C. (2019). The biological bases of colour categorisation: From goldfish to the human brain. *Cortex*. <https://doi.org/10.1016/j.cortex.2019.04.010> (in press).
- Smaers, J. B., & Vanier, D. R. (2019). Brain size expansion in primates and humans is explained by a selective modular expansion of the cortico-cerebellar system. *Cortex*. <https://doi.org/10.1016/j.cortex.2019.04.023> (in press).
- Staes, N., Smaers, J. B., Kunkle, A. E., Hopkins, W. D., Bradley, B. J., & Sherwood, C. C. (2018). Evolutionary divergence of neuroanatomical organization and related genes in chimpanzees and bonobos. *Cortex*. <https://doi.org/10.1016/j.cortex.2018.09.016> (in press).
- Thiebaut de Schotten, M., Croxson, P. L., & Mars, R. B. (2018). Large-scale comparative neuroimaging: Where are we and what do we need? *Cortex*. <https://doi.org/10.1016/j.cortex.2018.11.028>.
- Thiebaut de Schotten, M., & Shallice, T. (2017). Identical, similar or different? Is a single brain model sufficient? *Cortex*, 86, 172–175. S0010-9452(16)30346-X [pii]10.1016/j.cortex.2016.12.002.
- Vallortigara, G., & Rogers, L. J. (2005). Survival with an asymmetrical brain: Advantages and disadvantages of cerebral lateralization. *The Behavioral and Brain Sciences*, 28(4), 575–589. <https://doi.org/10.1017/S0140525X05000105>. discussion 589-633.
- Woods, C. (2010). *Visible language: Inventions of writing in the ancient middle east and beyond*. Chicago: Oriental Institute Museum Publications.