What did Einstein have that I don't? Studies on Albert Einstein's brain

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ABSTRACT

Introduction. The lives of those figures known for their innovative and revolutionary ideas have always inspired considerable interest and fascination. Different studies have examined what led these individuals to think so differently, and to what extent their genius was due to nature or nurture. In addition to helping provide a better understanding of the biological substrate of what we call genius, this research may contribute to favouring or nurturing the development of such geniuses. Albert Einstein is the best-known example of a scientist whose discoveries and theories revolutionised our view of the world and the history of science.

Development. In this article, we present a chronological and critical review of published studies on the peculiarities and idiosyncrasies, both macroscopic and microscopic, observed in Einstein's brain. We also relate the functional interpretations that have been given to those findings.

Conclusions. Researchers have described a number of differences and peculiarities in Albert Einstein's brain. Nevertheless, the functional significance of those anomalies, and the true anatomical substrate of his genius, remain topics open to debate.

KEYWORDS
Albert Einstein, brain, cerebral cortex, astroglia

Introduction

Human history is marked by the individuals who, because of their outstanding works or brilliant ideas, became known as geniuses. (The dictionary of the Royal Spanish Academy defines 'genius' as one possessing "an extraordinary mental ability to create or invent new and admirable things".) Learning everything there is to know about the lives of well-known geniuses is a fascinating task, since this knowledge may be applied to working out the riddle of whether geniuses are born or made. Deep down, we all would like to think that we might have the potential, at the very least, to be or become geniuses. And more importantly, who wouldn't be interested in knowing how to become a genius, or how to raise a genius child?

However, if we must finally concede that there is nothing noteworthy in the lives or educational backgrounds of these great figures, we are forced to conclude that geniuses are born and not made; rather, something in their biological make-up, genetics, or even their brains lends them the ability to think differently. For decades, these questions have resulted in studies of the morphological and physiological characteristics of the brains of great thinkers in order to determine the neurobiological features underlying their genius.

There can be no doubt that one of the best known examples of genius was Albert Einstein, considered the most brilliant scientist of the 20th century for his revolutionary contributions to our understanding of the workings of the universe.

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Development

Brief biographical sketch

Albert Einstein was born in the city of Ulm in Württemberg, Germany, on 14 March 1879. Six weeks later, his family moved to Munich, where young Albert would begin his studies at Luitpold Gymnasium. His early childhood was apparently normal, although many sources mention that his speech development was delayed; he did not speak until the age of 3. He also learned to play the violin as a child, and would remain an avid violinist for the rest of his life. The family later moved to Italy, and Albert continued his schooling in Aarau (Switzerland). In 1896, he enrolled in the Swiss Federal Institute of Technology in Zurich, where he studied to be a professor of mathematics and physics. In 1901, for lack of a teaching position, he accepted a job as a technical assistant at Switzerland's federal patent office.

In his free time during his years at the patent office, he completed the larger part of his voluminous works. It was in 1905 that he wrote several pivotal papers that were published in the prestigious journal *Annalen der Physik*, and their impact was such that 1905 became known as his *annus mirabilis* or miraculous year. The first manuscript explained Brownian motion, the second examined the photoelectric effect, and the other two presented special relativity and mass-energy equivalence. The University of Zurich awarded him a doctorate in 1906 for the first paper, and his work on the photoelectric effect would be honoured with the Nobel Prize in Physics for 1921. He was appointed associate professor in Zurich in 1909, and then offered a professorship in theoretical physics in Prague in 1911, although he returned to Zurich the following year to take a similar position. In 1914, he became the director of the Kaiser Wilhelm Institute for Physics, as well as a professor at the University of Berlin. He became a German citizen in 1914 and remained in Berlin until 1933, when he renounced that citizenship for political reasons. He left for the United States and was soon working as a professor of theoretical physics in Princeton. He became a citizen of the United States in 1940 and retired from his professorship in 1945.[1]

Extraction and preservation of Einstein's brain

On 17 April 1955, Albert Einstein experienced severe internal haemorrhaging caused by the rupture of an abdominal aortic aneurysm that had previously been surgically reinforced. Einstein is reported to have refused an additional surgical procedure, and he died the next morning at the hospital in Princeton. He was 76 years old. Thomas Stoltz Harvey, the pathologist at that hospital, removed Einstein's brain during the autopsy (some say without the family's permission, while others state that his son, Hans Albert, had authorised the procedure). Harvey extracted the brain within 7 hours of Einstein's death, preserved it, and performed the initial study. Harvey first weighed the fresh brain and then immediately fixed it by perfusing 10% formalin through the carotid arteries. The brain was later suspended in 10% formalin. After fixation, Harvey measured its dimensions and took carefully calibrated photos of all possible views of the brain, including after the hemispheres had been dried. Hemispheres were then sectioned into approximately 240 blocks measuring 10 cm^3, and their exact localisations were also recorded photographically. These blocks were preserved in celloidin and later sliced and processed histologically.[2]

Studies performed on Einstein's brain

It is intriguing to note that although Albert Einstein died in 1955, 30 years would pass before the first study of his brain would be published in the scientific literature. The first morphological study of Einstein's brain was carried out in 1985. This project studied only four histological slices from Brodmann areas 9 (prefrontal cortex) and 39 (posterior parietal cortex) bilaterally. These areas were selected because they form part of the multimodal association cortex, linked to the most complex cerebral functions. The prefrontal cortex is responsible for behaviour, attention, recent memory, abstract thinking, categorising information, and formulating and initiating actions. The parietal lobe, in turn, has been linked to the integration of visual, auditory, and somatosensory information. Neural activity was measured in this study by analysing the ratio of neurons to glial cells using slices stained with the Klüver-Barrera technique and comparing them to slices taken from 11 control subjects.[3]

Of the four analysed areas, only area 39 on the left side presented a significantly lower neuron-to-glial cell ratio in Einstein's brain than in the control subjects. The explanation proposed for this finding was that this area of Albert Einstein's brain must have been exceptionally active, and that maintaining this intense metabolic activity would have required a greater number of glial cells.[3]

This initial morphological study was criticised for many reasons: the mean age of the control subjects (64 years) differed considerably from Einstein's age at death (76 years), recruited controls displayed a very different socioeconomic level, and furthermore, researchers performing the quantitative analysis were not blinded to the data.[4]

A later study, published in 1996, measured the thickness of the cerebral cortex, as well as the number and size of neurons in the prefrontal cortex. Neurons in the cerebral cortex were similar in size and number to those observed in individuals of the same age. Nevertheless, since Einstein's cerebral cortex was much thinner than those of controls (2137 µm vs 2659 µm), his neuronal density was greater, that is, more neurons were counted per unit of area (46 995 vs 34 962 neurons/mm^3). Based on these observations, researchers proposed that this relatively higher neuronal density might result in a lower interneuronal conduction time, which would thus promote Einstein's intellectual abilities.[5]

The first study to examine Einstein's macroscopic cerebral anatomy by comparing photographs of his brain to those from a control group (35 men and 56 women) was published in 1999. The researchers concluded that frontal and temporal lobe measurements did not differ substantially from those of controls. Findings for cerebral dimensions and weight were also similar between Einstein and controls, and they clearly demonstrate that a large or heavy brain is not a necessary condition of having an exceptional intellect.

In general, the macroscopic anatomy of Einstein's brain was within normal limits, except for the parietal lobes. Here, the morphology of the Sylvian fissures of both hemispheres differed with respect to those of controls; they ended at an anterior location, and according to the authors, this resulted in absence of the parietal operculum. The same region of Einstein's brain was 15% larger than those of control subjects. These two traits suggest increased development of the posterior parietal regions during the early stages of brain formation. Another consequence of this rare finding was that Einstein's supramarginal gyrus was located posterior to the Sylvian fissure instead of being divided by a sulcus as would normally be the case. This study speculates that the anatomical peculiarities of the posterior parietal lobes might be related to Einstein's prodigious intellect, and especially to his visuospatial abilities. We should point out that this particularity in the parietal lobes (the larger size of the posterior parietal region) has also been observed in the brains of other celebrated physicists and mathematicians, such as Gauss and Siljeström.[2]

An additional microscopic study of Einstein's brain was published in 2006. This study made use of immunohistochemical analysis of glial fibrillary acidic protein (GFAP), a marker specific to the astrocytic cytoskeleton. In contrast with previous studies, this one produced a detailed description and quantitative measurement of the complexity of astroglial processes observed in the most superficial layer of the cerebral cortex (however, the cortical area or areas that were analysed are not specified). The study parameters included the parallelism, relative depth, and tortuosity of the astroglial processes. Einstein's brain was compared to samples from four correctly age-matched individuals with no history of psychiatric or neurological disease. Results from the analysed samples did not include any distinctive features, although the astrocytic processes from Einstein's brain were longer, with higher numbers of interlaminar terminal masses. The authors suggested that the increased length of astrocytic processes could have to do with greater membrane exposure by those astrocytes, which would favour higher numbers of receptors and channels and possibly increase the functional capacity of the glial cells. Nevertheless, the true significance of these findings remains uncertain because they have been observed in other diseases, including Alzheimer disease.[6]

Another study, published by Falk in 2009, provided a new analysis of the macroscopic photographs of Einstein's brain that had been examined by Witelson et al. Falk's analysis was based on techniques taken from palaeoanthropology, and it found additional differences with respect to control subjects. These included an unusual 'knob' on the postcentral gyrus of the right hemisphere, which was interpreted as secondary to Albert Einstein's noteworthy skill as a violinist; this finding had been previously reported in experienced musicians.[7] In turn, the structure of the left postcentral gyrus showed increased depth and amplitude of the regions representing the face and tongue. The same study followed up on differences previously observed in Einstein's parietal lobe, and it supported the hypothesis that these differences could be associated with his outstanding visuospatial and mathematical abilities. Lastly, Falk observed an unusual superficial cleavage in Brodmann area 40, with fusion of the rostral part of area 40 and the postcentral gyrus in the left hemisphere. These features could be related to Einstein's childhood language difficulties.[8]

The article published by Falk et al. in 2013 provides a new description of the external features of Einstein's brain, in addition to the first analysis of the sulcus pattern of the entire cerebral cortex. This analysis was based on 14 recently-discovered photographs, most of which were taken from unconventional angles. They provide the first views of medial regions of the cerebral hemispheres and insular cortex. In the course of the study, most of the sulci in Albert Einstein's brain were identified and the sulcal patterns in different regions were compared with those of 85 human controls that had been described in the literature. The new images of the frontal lobe confirm the presence of a large bulge on the right side in the area corresponding to the motor cortex for the left hand, plus an unusually large left motor cortex for the areas representing the face. Both hemispheres of the cerebral cortex showed numerous gyri to either side of the medial frontal sulcus, which implies that the volume of the prefrontal association areas of Einstein's brain were at the high end of the range shown by the control brains. In contrast with previous reports, these authors' description of the parietal lobes states that the left parietal operculum is indeed present. The temporal lobes showed no significant differences, whereas the occipital lobes were fuller along the rostral-dorsal boundary, with highly developed convolutions on the medial surface of the visual cortex in both hemispheres. Overall, the authors concluded that Einstein's brain is not spherical and certainly not symmetrical. They support the hypothesis that these particularities of the German-born physicist's cerebral cortex were probably related to his exceptional visuospatial and mathematical abilities.[9]

Using the recently-discovered photographs of Albert Einstein's brain, Men et al. recently completed a morphometric analysis of the corpus callosum intended as an indirect measurement of interhemispheric connectivity. The study drew from the two photos showing the medial surface of the encephalon. These researchers made comparisons by performing similar morphometric studies using magnetic resonance images in two control groups; the first included 15 subjects aged 70 to 80 years, and the second included 52 right-handed men aged 24 to 30. They used a mathematical method to calculate the thickness of Einstein's corpus callosum all along that structure and compared the result to the thickness measured in both control groups, the younger and the older subjects. The researchers found that Einstein's corpus callosum was considerably thicker at almost every location than was the case for the age-matched controls. It was also significantly thicker at the rostrum, genu, isthmus, and especially the splenium compared to measurements from young control subjects. These findings were obviously interpreted as indicating that Albert Einstein's brain possessed an exceptional ability to communicate between its two hemispheres, which once again might be associated with his prodigious intellectual abilities.[10]

No further studies of Albert Einstein's brain have been published to date, but we should point out that of the 240 blocks of preserved tissue, only 180 can be located (at the University Medical Center of Princeton). There are also 567 histological slides which are kept by the National Museum of Health and Medicine in Washington D.C. The whereabouts of the remaining material are a mystery, but it may form part of the private collections of certain prominent doctors and researchers. Such was the fate of Einstein's eyes, which were removed during the autopsy by his ophthalmologist, who then kept them.[9]

Conclusions

Understanding the cause or substrate underlying genius never fails to fascinate us, because every one of us would like to know how genius comes to be. There are obvious advantages to discovering a true 'formula' for creating geniuses, since every time such a person appears on the scene, scientific, technological, or artistic breakthroughs are soon to follow. The benefits for humanity would be significant. Nevertheless, we still have no clear answers with regard to the making of genius. Neither can we say whether geniuses are produced by nature or nurture, and, worst of all, we have no clear definition of 'genius'. For all of these reasons, Albert Einstein's brain has received a considerable amount of attention throughout the years, and yet it still remains shrouded in uncertainty and mystery.[11]

Einstein was an irrefutable genius, and the studies performed to date have reported multiple microscopic and macroscopic differences and peculiarities in his brain. Nevertheless, the functional significance of these peculiarities remains completely unexplained; most attempts at determining function from form are largely speculative, and these conclusions are to be interpreted carefully.[11] We believe that studies of Albert Einstein's brain leave us with more questions than answers, but, as in any scientific undertaking, this process in itself may be valuable. The researchers responsible for these different studies have repeatedly dedicated their best and most meticulous efforts to finding differences between selected parts of Einstein's brain and those of control subjects. In light of this pursuit of peculiarities, is it not logical to believe that we might find them some day? Some of the studies detected only slight differences with respect to control groups. One possibility is that their findings merely reflect the substrate of individual variation, which is inherent to all forms of life. Other studies suggest that some of the macroscopic changes had actually been present since the formation of Albert Einstein's embryonic brain. Could this mean that Einstein was predestined to become a scientist and develop his visuospatial and mathematical abilities? Or was it his personal and environmental circumstances that led him to this end? Is it possible to ascertain which of the listed structural anomalies were congenital, and which were moulded by his experience, learning, limitations, disorders, and diseases?

Given the technique used to preserve the brain, very few additional studies can be performed using existing tissue samples. It would have been marvellous if he had ever had the opportunity of being studied with functional magnetic resonance imaging while solving an equation or pondering his theory of relativity. However, considering how little we know now, we might suppose that even MRI data would lead us to wonder if the activation observed in his brain was really so different from that occurring in control subjects. Perhaps the main issue is that we still do not know which changes or differences should be scrutinised, or where they are located. For now, the answers to these questions and other transcendent conundrums will have to wait.

Conflicts of interest

The authors have no conflicts of interest to declare.

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