Commentary

DOI: 10.5582/bst.2014.01045

Revisiting Einstein's brain in Brain Awareness Week

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Summary **Albert Einstein's brain has long been an object of fascination to both neuroscience specialists and the general public. However, without records of advanced neuro-imaging of his brain, conclusions regarding Einstein's extraordinary cognitive capabilities can only be drawn based on the unique external features of his brain and through comparison of the external features with those of other human brain samples. The recent discovery of 14 previously unpublished photographs of Einstein's brain taken at unconventional angles by Dr. Thomas Stoltz Harvey, the pathologist, ignited a renewed frenzy about clues to explain Einstein's genius. Dr. Dean Falk and her colleagues, in their landmark paper published in Brain (2013; 136:1304-1327), described in such details about the unusual features of Einstein's brain, which shed new light on Einstein's intelligence. In this article, we ask what are the unique structures of his brain? What can we learn from this new information? Can we really explain his extraordinary cognitive capabilities based on these unique brain structures? We conclude that studying the brain of a remarkable person like Albert Einstein indeed provides us a better example to comprehensively appreciate the relationship between brain structures and advanced cognitive functions. However, caution must be exercised so as not to over-interpret his intelligence solely based on the understanding of the surface structures of his brain.**

Keywords: Albert Einstein's brain, cerebral cortex, cognitive function, Thomas Stoltz Harvey, brain photography

1. Introduction

This March, as we celebrate the achievements made in neuroscience and raise awareness of brain health in our communities around the world, it is fitting to re-visit one of the most fascinating brains on earth, that of Albert Einstein - the brain of a true genius. As a group of science students, we are fascinated by what is under his brain, a finite boundless spherical universe. In particular, we are drawn to a recent study of the cerebral cortex of Albert Einstein based on newly discovered, previously unpublished photographs of Einstein's brain (*1*). What is unique about the structures of his brain? What can we learn from this new information? Can we explain his extraordinary cognitive capabilities based on his unique brain structures? These are just a few of the questions we will focus on in this short review article.

To gain a better understanding of the cognitive functions related to the structures of Einstein's brain, we collected and critically reviewed all published papers describing Einstein's brain, including a recent report by Falk and her colleagues (*1*). A battery of unusual external features of Einstein's cerebral cortex is discussed in the paper. A comparison of these features with known human brain structures reported in the literature revealed several interesting features of Einstein's brain previously unknown to us.

After Einstein's death in 1955, his brain was carefully dissected, photographed and preserved by Princeton Hospital pathologist Dr. Thomas Stoltz Harvey. Dr. Harvey cut the brain into 240 pieces; some were sent to researchers for examination. Efforts were made to identify unusual anatomical features in particular on the cerebral cortex to account for Einstein's genius (*2-5*). It is only until recently a detailed description of the surface anatomy of the entire

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cerebral cortex of Einstein's brain was reported by Dr. Falk and colleagues (*1*). New findings were revealed in this study based on 14 previously unpublished photographs taken by Dr. Harvey. Importantly, these photos were apparently taken at unconventional angles, which showed unusual morphological features when compared with the external features of other 85 human brain samples described in previous studies by Connolly (1950) (*6*) and Ono *et al*. (1990) (*7*). All external surfaces of the cerebral cortex, the medial surface of each hemisphere and the insula of the right hemisphere were imaged on these photographs. New surface sulci of Einstein's cerebral cortex were identified and a road map to the 240 blocks of brain sections was provided for future investigators. Although limited by the information available on the photographs, the unusual features of Einstein's brain are good indications of extraordinary cognitive capabilities based on our current understanding of cognitive process of humans.

2. What is unique about the structures of his brain?

Based on the descriptions by Falk *et al.*, (2013) (*1*), a summary of the unusual anatomical features of Einstein's cerebral cortex is listed below.

2.1. *The frontal lobes*

i). A large 'knob'-shaped fold in the right hemisphere representing enlarged motor cortex area for the left hand;
ii). The pre-central superior sulcus is continuous with the pre-central inferior sulcus in both hemispheres, forming a long, continues sulcus. The pre-central inferior sulcus terminates extraordinarily high above the Sylvian fissure in the left, but not the right, hemisphere. Diagonal sulcus exists in both hemispheres;
iii). The presence of unusually long and continuous mid-frontal sulcus on the right hemisphere which divides the middle frontal region into two distinct gyri, giving rise to four frontal gyri rather than the typical three gyri;
iv). A long, branched inferior frontal sulcus and an additional triangular sulcus in the left hemisphere, which are located in the pars triangularis;
v). The caudal segment of the inferior frontal sulcus is connected with both the diagonal sulcus and the pre-central inferior sulcus in the left hemisphere.

2.2. *The parietal lobes*

i). Morphological features suggest expanded primary sensory and motor representations of face and tongue in the left hemisphere;
ii). The left Sylvian fissure is separated from the postcentral inferior sulcus by a submerged gyrus;
iii). A significantly larger volume of grey matter in the angular gyrus in the left hemisphere than that in the right hemisphere;
iv). The left superior parietal lobule is separated from the inferior parietal lobule by a continue sulcus in the left hemisphere, while the two lobules are separated by two parallel sulcus in the right hemisphere;
v). The united segments of the intraparietal sulcus on the right side course upward into the superior parietal lobule, rather than along its inferior border.

2.3. *The temporal lobes*

i). Expanded superior surface of the posterior part on the left side than on the right;
ii). Collateral sulcus is divided into two separate segments in the left hemisphere.

2.4. *The occipital lobes*

i). The anterior occipital sulcus in both hemisphere are relatively caudal, which might be caused by expansion of inferior parietal lobules;
ii). A separate medial segment of the transverse occipital sulcus on the left hemisphere that crosses its superior margin;
iii). A relatively large additional transverse occipital sulcus in the right hemisphere (This variation is not included in articles by Ono (1990) (*7*) and Connolly (1950) (*6*)).
iv). Presence of four transverse occipital sulci;
v). Relatively large additional transverse occipital sulcus in the right hemisphere, indicating relatively wide occipital lobes near their dorsal rostral borders.

2.5. *The medial and internal surfaces of the brain*

i). The marginal sulcus ends at the superior medial border instead of extending on the dorsolateral surface of the brain on the medial surface of the left hemisphere;
ii). There are four inferiorly directed branches of cingulate sulcus on the left hemisphere and unnamed sulci in the middle of cingulate gyri in both hemispheres, indicating that the cingulate gyri may have been relatively convoluted;
iii). No limb of the H-shaped subparietal sulcus crosses the superior margin of the right hemisphere;
iv). The cuneus of the left hemisphere are relatively ramified, containing inferior and superior sagittal sulci;
v). The superior sagittal sulcus and the parieto-occipital sulcus are connected in the left hemisphere;
vi). In both hemispheres, parieto-occipital incisures are distinct from each other and just caudal to the

limiting sulcus of the precuneus. The cunei are found unusually convoluted.

2.6. *Patalia pattern*

The left occipital lobe is lower, wider towards the posterior end than the right occipital lobe. The right frontal lobe is wider in the anterior end than the left frontal lobe. These features contribute greatly to the asymmetry of Einstein's brain.

3. What can we learn from this new information?

The highly advanced cognitive abilities in humans have been attributed to an evolutionary increase in both the overall brain size (*8*) and neurological reorganization (*9*) manifested by an asymmetry of the cerebral hemispheres and some of their subareas (*10,11*). Although there is no evidence to suggest Albert Einstein's brain is exceptional in size (*2*), the external neuroanatomic features of his cerebral cortex involved in specific higher cognitive functions appear to be especially marked.

The following lists important features. For example, the convoluted Broca's speech area of his brain can be interpreted as having higher speech abilities. The enlarged 'knob' in the right primary motor cortex corresponds to the left hand, which may attribute to Einstein's early extensive violin training (*12*). The expanded lower parts of the primary sensory and motor cortices in the left hemisphere indicate enhanced sensory of the face and tongue (*5,13*).The relatively expanded left inferior parietal lobule suggests relatively great skills on language, body image and mathematics. In particular, the expanded left angular gyrus facilitates the recognition of visual symbols and sensory language (*1*). Einstein's right superior parietal lobule may be larger comparing with the left, which are thought to be involved in certain aspects of visuospatial imagery (*14*). The convoluted medial surfaces of the occipital lobes including primary visual area BA 17 as well as associated visual areas BA 18 and BA 19 may be significant during processing visual information (*15,16*). The inferior temporal gyrus is relatively expanded on the basal surface of each hemisphere, which can be interpreted as having better developed high-level processing capabilities associated with remembering, recognizing and naming of visual objects and forms (*1*). The medial surfaces manifest larger frontopolar region, especially for anterior cingulate cortex, which gives implications about neurological substrate for the enhanced ability in handling conflicting impulses needed in self-regulating behavior (*17*).

Despite of the details provided based on the photographs, it is possible that some of the descriptions are not accurate due to the fact that analysis was based only on old monochrome photographs rather than the real brain. Possibility exists that the cortical convolution was actually not as exaggerated as described. Indeed, this kind of mistake occurred before. For example, earlier studies regarded Einstein's posterior ascending limb of the Sylvian fissure as confluent with the postcentral inferior sulcus based on the photographs (*2*). However, new photographs taken from another angel revealed that the two sulci (fissure) were, in fact, separate (**1**). Therefore, caution must be taken when conclusions are drawn from these photographs.

Many unusual features of Einstein's brain were identified based on the comparison of Einstein's brain with descriptions provided in two previous studies of 60 (*6*) and 25 (*7*) human brains. Because these two studies did not provide accurate records of the brain samples in terms of race, age and sex, etc., the reliability of the identified "unusual features" of Einstein's brain is limited and depends on the accuracy of the two reports. For example, in the study of Connolly *et al*. (1950) (*6*), half of the brains were from white Germans; the other half were from black Americans. Sample sex, but not age, was reported. In the study of Ono *et al*. (1990) (*7*), most of the specimens were assumed to be Europeans with age and sex unknown. It is obviously necessary and ideal to match factors such as race, sex and age when comparing brain structures, which may lead to the identification of more unusual features and elimination of possible artifacts.

One of the pictures revealed that Einstein's left Sylvian fissure was non-confluent with the postcentral inferior sulcus and it was suggested that the right hemisphere was also the same, assuming from the similar external sulcal patterns of the surrounding region. This assumption may be unreliable as the layout pattern of the cerebral cortex is asymmetric which makes it rather difficult to predict features of the opposite hemisphere.

4. Can we explain his extraordinary cognitive capabilities based on his unique brain structures?

Einstein has extraordinary cognitive abilities including maintaining attention, performing visuospatial tasks and mathematical thinking, which facilitate his thought experiments (*1*). The anatomical basis might lie in the pattern of Einstein's prefrontal cortex including the anterior portion of the frontal lobes (BA10). The prefrontal cortex is critical for a group of high-level cognitive processes including working memory, reasoning, task flexibility, and problem solving as well as planning and execution (*18,19*). In Einstein's case, his cortex appears to be highly convoluted in both hemispheres, which may explain his remarkable cognitive strength.

However, more convoluted brain areas may not necessarily correlate with enhanced cognitive functions. For example, the unusually convoluted Broca's area, relatively expanded left inferior parietal lobule and expanded interior parts of Einstein's left primary somatosensory area, and the left primary motor cortices representing face and tongue are considered to be involved in language skills, especially speech abilities (*1*). But we did not find sufficient evidence suggesting that Einstein exhibited extraordinary abilities in such things. In fact, Einstein is an introvert and probably not a good speaker (*20*).

How to tease out brain structural changes due to "nature", but not "nurture", is another difficult issue when trying to interpret Einstein's genius based on his final brain structures. For example, a large ‘knob'-shaped fold representing the left hand in the motor cortex of Einstein's right hemisphere can probably be attributed to long time violin training during Einstein's early age. This unusual feature has been seen in some long-time right-handed violinists. A study by Hyde *et al*.(2009) (*21*) has shown that brain structure changes in the frontal, temporal and parieto-occipital lobes in children around the age of six after 15 months of keyboard training (*21*). Another study by Christian Gaser demonstrated that gray matter volume increased in the brains of musicians (*22*). This type of alteration of brain structures due to "nature" has also been reported in animals. For instance, the primary somatosensory area of raccoon's forepaw used for exploring the environment is greatly enlarged and the areas controlling the palm pad and digit area in the forepaw are also separated by sulci (*23*). It is not possible at this stage to determine if some of Einstein's unusual brain structures were in fact "nature", or "nurture".

It is also worth noting that in addition to external brain morphology, other factors, such as cortical thickness, neuronal density, the neuron to glia ratio, and brain chemicals, those also play important parts in a person's mental activities. These information is obviously not available to us, which make it very difficult to fully understand Einstein's brain. Furthermore, we must not over interpret Einstein's brain. Because interpretation bias occurs when people are constantly aware that they are looking at the famous Einstein's brain rather than a brain of unknown identity. In psychology, this is termed as observer-expectancy effect, in which the observer is unconsciously affected by the expectation of certain results (*24*). Such a bias can be controlled with a blinded experimental design approach. It is necessary to choose observers who are not aware of the identity of the brain samples and to derive at their conclusions independently.

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(Received March 31, 2014; Revised June 10, 2014; Re-revised October 17, 2014; Accepted October 17, 2014)